Evolutionary Psychology and Stone Tool Production: An Examination of Novice Blow Strength Judgement in a Knapping Task

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Abstract

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Despite representing an approach to psychology that places the most emphasis on the importance on the role of our ancestral past in shaping the human cognitive architecture, Evolutionary Psychology remains largely neglected in the field of archaeology. Though archaeologists have incorporated approaches into their research that adopt both cognitive and evolutionary perspectives, the lack of engagement with the concepts and methodologies of Evolutionary Psychology arguably risks the abnegation of valuable opportunities for interdisciplinary collaboration that could greatly benefit both fields.

This research applies the methodology of Evolutionary Psychology to the study of stone tool production, which is arguably the most abundant source of evidence from our ancestral environments regarding past cognition. The research provides an assessment of the adaptive advantages and information-processing problems of the various task domains associated with stone tool producing behaviours, together with considerations of possible test designs from the perspective of Evolutionary Psychology. The data collected relating to novices' judgment of blow strength adopting a mixed-methods, explanatory sequential test design are also presented. The results are then evaluated to determine the extent to which a posited cognitive bias for acquiring competence in blow strength judgement is supported.

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Statement of Copyright

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Chapter 1: Introduction

> It is self-evident that simple conchoidal flaking must be easy or it would not have appeared so early in our evolution. A hominid ancestor of modern Man, *Homo habilis*, made simple but perfectly usable flaked stone tools more than one and a half million years ago. (Cotterell, Kamminga, & Dickinson, 1985: 220)

> Many psychologists avoid the study of natural competences, thinking that there is nothing there to be explained […] But our natural competences […] are possible only because there is a vast and heterogenous array of complex computational machinery supporting and regulating these activities. This machinery works so well that we don't even realize that it exists -- We all suffer from instinct blindness. As a result, psychologists have neglected to study some of the most interesting machinery in the human mind. (Tooby & Cosmides, 1997)

Following its inception in the late 1980's, Evolutionary Psychology[1], as conceived by Tooby and Cosmides (Tooby & Cosmides, 1989, 1992), has burgeoned into a thriving field in psychology. This fact notwithstanding, and despite its explicit focus on the importance of gleaning information from past environments, it has been widely shunned by researchers working in the field of archaeology generally, and in the sub-discipline of evolutionary cognitive archaeology specifically (Wynn, 2009: 146). This lack of interdisciplinary engagement is arguably to the detriment of both fields, and potential therefore remains for mutually beneficial collaboration both in terms of establishing novel methods of generating data and in providing fresh challenges to the prevailing assumptions that exist in both fields.

[1] Within the literature it has become conventional (and this convention will be maintained throughout this thesis) to use the upper case to refer to the form of Evolutionary Psychology espoused by scholars such as Buss (1995, 1999) and Tooby and Cosmides (1992, 2005). As Scher and Rauscher note, however, other forms of evolutionary psychology (typically described using the lower case) are conceivable that do not make the same epistemological commitments (Scher & Frederick Rauscher, 2003).

It is hoped that this thesis will redress this imbalance to an extent. The overall aim of the thesis is to apply the methodology of Evolutionary Psychology to studying stone tool producing behaviours. Due to the paucity of research from the perspective of Evolutionary Psychology relating to stone tool production, much of the conceptual work regarding the application of its methodology to this domain remains to be done. To this end, as will be described below, Chapters 3 to 7 consider how stone tool producing behaviours can be examined from an Evolutionary Psychologists perspective. Finally, the ultimate aim of the thesis is to devise methods of testing for putative 'psychological mechanisms' within the human cognitive architecture that are devoted to solving the types of problems associated with stone tool production. This area is covered by Chapters 8 and 9, also described below.

Chapter 2 provides an account of the main tenets of Evolutionary Psychology as conceived by Tooby and Cosmides (1992). With an overall focus on examining the evolved psychological mechanisms that comprise the human cognitive architecture, I outline Evolutionary Psychology's commitment to a number of interdependent claims regarding the modular, domain-specific nature of psychological mechanisms, the role that natural selection has played in shaping these mechanisms to solve recurrent adaptive problems, and the importance of the concept of the 'Environment of Evolutionary Adaptedness' for defining the adaptive problems encountered in past environments.

I then outline the proposed six-step methodology employed by Evolutionary Psychology, followed by an account of four prominent criticisms of the field. Finally, I describe two case studies, one of which represents a rigorous application of the methodology of

Evolutionary Psychology (a study focusing on the logic of social exchange), and one which suffers from some of the weaknesses highlighted by critics (a study on fire learning).

Chapter 3 assesses the current state of cognitive archaeology as a discipline, with a particular focus on evolutionary-cognitive archaeology. The advantages and limitations of the two main methods utilised within evolutionary-cognitive archaeology (namely, the 'final product' method and the *chaîne opératoire*) are considered, alongside two related approaches that are currently considered integral to evolutionary-cognitive archaeology, but whose data sets are nevertheless of relevance to the field: namely, neuroscience and lithic experimentation and replication. Finally, Chapter 3 includes a consideration of the prospective contributions that Evolutionary Psychology can make to the study of stone tool production. It is argued that adopting the perspective of Evolutionary Psychology has the potential to challenge some of the existing assumptions on which current studies into stone tool production are predicated, while also forwarding alternative methods of testing and data collection, which in turn have the potential to identify novel cognitive capacities associated with stone tool production.

The fourth chapter begins initially by arguing that applying the methodology of Evolutionary Psychology to the area of stone tool production requires, as a first step, that the distinct problem types involved be demarcated. To this end, I adopt the broad distinction between stone tool production techniques (i.e., the physical means of applying a blow) and methods (i.e., the application of several blows in sequence), before further demarcating these areas into hard and soft hammer percussion (for techniques) and the biface and Levallois (for methods).

Chapter 4 then focuses on the area of technique to ascertain whether hard and soft hammer percussion fulfil the criteria of an adaptive problem. Definitions are initially provided for each technique, together with a description of how the techniques can be identified archaeologically. The remainder of the chapter focuses on examining the extent to which the archaeological evidence can be used to demonstrate that hard and soft hammer percussion fulfil the criteria employed by evolutionary psychologists to identify an adaptive problem: i.e., the problem type must be reliably recurrent and have consequences relating to fitness (i.e., survival or reproduction).

Chapter 5 examines the extent to which stone tool production methods fulfil the criteria employed by Evolutionary Psychologists to identify a viable adaptive target. As with Chapter 4, definitions are initially provided for each method, together with a description of the means available to archaeologists to identify their use from lithic assemblages. The remainder of the chapter concerns an examination of the extent to which archaeological evidence can support the claim that stone tool production methods represent adaptive problems. Again, this involves establishing that the problem types were reliably recurrent, with accompanying consequences relating to survival or reproduction.

Chapters 6 and 7 consist of task analyses for the hard and soft hammer percussion techniques and the biface and Levallois methods respectively. The task analyses include a detailed consideration of the information-processing problems implicated in the use of the stone tool production techniques and methods under consideration. In Chapter 6, I draw on evidence from expert knappers, together with data from experiments in fracture mechanics, to identify the main variables that contribute to the success or failure of a flake removal when utilising hard or soft hammer percussion. In Chapter 7, I draw on evidence from refits of lithic materials recovered in archaeological contexts (where available), as well as the interpretations and reconstructions of modern knappers to identify the information-processing problems associated with the biface and Levallois methods.

Finally, both Chapter 6 and Chapter 7 conclude with a consideration of whether the information-processing problems associated with each of the techniques and methods under consideration comprise specific domains when compared both to each other and to other manual tasks. This is an important step in the methodology of Evolutionary Psychology in order to assess whether the problem-types described could be solved by psychological mechanisms that evolved to address similar problems, thereby raising the possibility that stone tool producing behaviours represent a by-product of pre-existing cognitive structures.

In Chapter 8, I consider potential experimental test designs to examine whether psychological mechanisms dedicated to facilitating the learning of stone tool producing behaviours are present in the human cognitive architecture. To this end, Chapter 8 commences with a consideration of the general process of test design in psychology, focusing on the identification of variables and the means of manipulating these variables in an experimental setting to examine a proposed causal relationship. I then expand on this general framework by specifying the commitments made by evolutionary psychologists during the test design process, noting that any test design devised from the perspective of Evolutionary Psychology should target the most adaptively relevant facet for the task domain under consideration.

The devised working hypothesis is that, all other things being equal, test subjects will learn to solve the information-processing problems associated the technique/method task domains most efficiently when the raw material employed exhibits fracture properties consistent with those reliably encountered by our ancestors in past environments. Finally, Chapter 8 outlines an 'in principle' test design for data gathering, together with a consideration of the prospects of carrying out such tests in practice.

Chapter 9 outlines the mixed methods, explanatory sequential design devised to collect data relating to various aspects of novice performance during a knapping task. The experimental design consists of two distinct phases: a first phase of quantitative data collection followed by second phase of qualitative data collection. The specific focus of the test design in the first phase was to examine novice knappers' ability to accurately judge, and consistently apply, blow strengths in two differing conditions: for blow strengths consistent with those typically used for a knapping task, and for blow strengths that deviate from that range.

The first half of Chapter 9 provides a description of the research design for the quantitative phase, including details of the demographics of the 12 test participants, the apparatus and materials used, and the phases involved in the test procedure. The second half of Chapter 9 provides a description of the research design for the qualitative phase, which was developed to address potential problems identified while collecting the quantitative data. As with the first phase, details are provided of the demographics of the 12 test participants, the apparatus and materials used, and the phases involved during the testing process.

Chapter 10 presents the data collected in the quantitative and qualitative phases in accordance with the methodology described in Chapter 9. The quantitative results describe how the 12 test participants performed when applying 10 hammerstone blows in two sets of conditions: when using their own judgement and after instruction was provided regarding the ideal blow strength to apply. The degree of consistency evidenced in the performance of the 12 test subjects is assessed by comparing the respective measures of central tendency (mean and median) and measures of variance (standard deviation).

The qualitative results are described for 10 of the test participants from the first phase, plus 2 additional test subjects. Again, test subjects were asked to apply 10 hammerstone blows in two sets of conditions: when approaching the task as they saw fit and after viewing video footage of an expert knapper reducing a core. Data were collected of the choices made by test participants regarding body position, core grip, hammerstone grip, blow height, and the lateral movement of the blows applied. The qualitative results describe the initial choices made by test participants in each of the categories mentioned above, together with any changes made after viewing footage of the expert knapper and any comments relating to the underlying motivations for how they performed in the task.

Finally, Chapter 11 brings together the main findings of the thesis as a whole, including a critical evaluation of the quantitative and qualitative data, a discussion of the limitations of the study together with the implications for future research in this area, and, finally, the overall conclusions of the research.

Chapter 2: Evolutionary Psychology: Concepts, Criticisms and Case Studies

2.1. Introduction

Chapter 2 provides an overview of Evolutionary Psychology, focusing primarily on the work of Tooby and Cosmides (Cosmides & Tooby, 1987; Tooby & Cosmides, 1989, 1990a, 1992, 1997, 2005, 2006). Evolutionary Psychology is characterised by the view that the human psychological architecture is composed of many evolved mechanisms that are specialised for solving the long-enduring adaptive problems of our evolutionary past (Tooby & Cosmides, 1992). It consists of a set of interrelated claims concerning the function of the human cognitive architecture, how this cognitive architecture was formed, and how best to approach its study.

To outline the main tenets of Evolutionary Psychology I will first outline the concept of the 'evolved psychological mechanism', which represents the causal link between the evolved structures of the brain and manifest behaviour. I will then discuss the claim made by Evolutionary Psychologists that the psychological mechanisms that comprise the human cognitive architecture are adaptations, together with two corollaries of this view; that the brain will exhibit domain-specificity and that the human cognitive architecture will be species-typical in functional terms. I will then outline the concept of the 'Environment of Evolutionary Adaptedness' as proposed by Evolutionary Psychologists, together with the perceived repercussions regarding the best approach to analysing the human cognitive architecture.

Finally, I will provide an outline of the methodology of Evolutionary Psychology, a discussion of the four main criticisms of the field, together with two case studies, one of which represents a robust application of the methodology of Evolutionary Psychology (Cosmides and Tooby's research into the logic of social exchange), and one which suffers from some of the weaknesses highlighted by critics (Fessler's study on fire learning).

2.2. Evolved Psychological Mechanisms

Evolutionary Psychologists claim that much evolutionary oriented research into human characteristics is misguided due to the fact that it mistakenly seeks to apply evolutionary theory directly to behaviour. Cosmides and Tooby argue that it is not possible for natural selection to select for behaviour as such, but only for those physical 'mechanisms' that produce it (1987: 281). The concept of the evolved psychological mechanism therefore represents a corner stone of Evolutionary Psychology; such mechanisms are seen as the causal link between the evolutionary process and manifest behaviour:

> 'It is these mechanisms that evolve over generations; within any single generation it is these mechanisms that, in interaction with environmental input, generate manifest behaviour. The causal link between evolution and behaviour is made through the psychological mechanism.' (Cosmides & Tooby, 1987: 277)

To define a psychological mechanism, it is first necessary to note that Evolutionary Psychologists explicitly adopt the view that the brain is, in essence, a computer; its function is to '...extract information from the environment and use that information to generate behaviour and regulate physiology' (Tooby & Cosmides, 2005: 16). Within this information-processor model of the brain, psychological mechanisms are viewed as 'minicomputers' dedicated to solving problems within a particular domain (with the human cognitive architecture as a whole being the total set of these mechanisms that jointly generate behaviour) (Cosmides & Tooby, 1987: 282; Tooby & Cosmides, 1997: online).

Evolutionary Psychologists suggest that the focus upon evolved psychological mechanisms (and their information processing properties) represents a necessary shift in terms of the level of analysis when considering the functional organisation of the human cognitive architecture. Analysis at the level of behaviour, as suggested above, bypasses a step in the causal chain and erroneously focuses on the 'output' of the underlying cause. For Tooby and Cosmides this only serves to obfuscate any underlying functional uniformity that might exist (given the seemingly infinite array of possible behavioural responses) (1992: 64). At the other end of the scale, analysis at the neurobiological level raises various problems due to both the complexity of the human cognitive architecture and limits of the approach (Cosmides & Tooby, 1987: 282; Tooby & Cosmides, 1992: 66)[2]. The appropriate level of analysis, Tooby and Cosmides argue, is the cognitive level:

> 'For the purposes of discovering, analyzing, and describing the functional organization of our evolved psychological architecture, we propose that the information-processing language of cognitive science is the most useful.' (1992: 63-64)

The cognitive level represents the level of 'proximate causation' of behaviour, where psychological mechanisms can be described in functional terms (i.e. in terms of the

[2] Though they argue that it is erroneous to apply evolutionary theory directly to behaviour, Tooby and Cosmides do not suggest the same is true for the neurobiological level. However, they do argue that explanations framed in cognitive language, far from being a 'soft, optional activity that goes on until the "real" neural analysis can be performed', actually represent 'an unavoidable and indispensible step in the neuroscience research enterprise' (Tooby & Cosmides, 2006: 183)

information processing role that they perform) regardless of the underlying neurobiological structure (Cosmides & Tooby, 1987: 283-284).

As Hagen and Symons note, the view that the brain is an information processor is central to cognitive science in general (2007: 41). What distinguishes Evolutionary Psychology is the view that the brain, as a collection of computational devices, '...evolved to facilitate or enable reproduction in ancestral environments...' (Ibid). For Evolutionary Psychologists this second step is essential for explaining the complex functional organisation of the brain. Evolutionary theory provides an answer to the question of what kinds of problems the human cognitive architecture was 'designed' to solve, which can be used as a starting point in any analysis of how a given mechanism processes information (Cosmides & Tooby, 1987: 285). So besides stressing the information-processing role of the brain, and its role in regulating behaviour in response to internal or external inputs, Evolutionary Psychology places an emphasis on the view that the structure of the brain has been functionally organised by natural selection (Tooby & Cosmides, 1992: 66).

2.3. Adaptationism, Domain Specificity and Species-Typicality

For Tooby and Cosmides, a necessary corollary of the view that the psychological mechanisms that comprise the brain have been shaped by natural selection is that they will be adaptations, because '...adaptive problems are the only kind of problem that natural selection can design machinery for solving' (2005: 22).

In defining what constitutes an adaptive problem, Tooby and Cosmides propose that there are two necessary conditions that need to be met. First, they need to be long-enduring, recurrent problems that our individual ancestors encountered during evolutionary history; secondly, they need to be the kind of problem that affects reproduction, or the reproduction of relatives (2005: 21-22). The former is necessary in order for the process of evolution to have time to affect any modifications in design. The latter is necessary for selection to occur, with selection acting on the psychological mechanisms in the brain, developing complex functional design, just as it acts on other physiological features.

Though it is acknowledged that adaptations are not the only products of the evolutionary process[3], they argue that it is possible to identify adaptations through their complex functional organisation, which is seen as the 'signature' of selection (Tooby & Cosmides, 1992: 62). So in addition to the view that the human cognitive architecture consists of information processing psychological mechanisms, Evolutionary Psychologists are also committed to the view that the function of a given psychological mechanism will be closely associated with a given adaptive problem.

For Tooby and Cosmides there are two further consequences of the claim that psychological mechanisms are adaptations shaped by natural selection: namely, that the human cognitive architecture will exhibit both domain specificity and species typicality.

To support the claim that the structure of the brain will be domain specific, Tooby and Cosmides argue that the adaptive problems that existed in ancestral environments would have been wide and varied, to the extent that no general-purpose information processing

[3] For example, evolutionary processes can produce beneficial 'by-products', which are features of an organism that incidentally produce an adaptive outcome within a given context, despite the fact that they are not adaptations to that context. So an adaptation that prompts behaviours to anticipate and avoid stampeding herbivores in past environments might prove beneficial in modern environments for avoiding being struck by traffic, but it cannot be said to be an adaptation *for* avoiding being struck by traffic.

mechanism (or small number of general-purpose mechanisms) could produce an adaptive response in every instance, and as a result: '...natural selection will ensure that the brain is composed of [...] programs [...] which will be specialized for solving their own corresponding adaptive problems' (Tooby & Cosmides, 2005: 17). A domain, therefore, is viewed as an adaptive problem where the kind of problem differs from any other to the extent that it is most efficiently solved by its own dedicated information processing structure.

Furthermore, it is argued that it is likely that the brain comprises a large number of domain-specific psychological mechanisms because of the varied nature of the adaptive problems faced in our evolutionary past:

> 'To the extent that the demands of different adaptive tasks are different in nature, and more efficiently solved using different means, psychological mechanisms will tend, over evolutionary time, to multiply in number and differentiate in procedure.' (Tooby & Cosmides, 1989: 31)

Buss adopts the same view, arguing that though general solutions to adaptive problems may work in some instance, they will be prone to error (and may therefore prove maladaptive). A successful solution to a specific problem is inextricably linked to the specifics of that problem (Buss, 1999: 52). When considering a domain such as mate choice, for example, the kinds of adaptive problems that need to be addressed will vary significantly from a domain such as predator avoidance.

For Symons, adopting the view that the brain consists of domain specific mechanisms is a necessary step in bringing evolutionarily oriented research into the brain in line with approaches to the rest of physiology. Indeed, he argues that the notion of a predominantly domain-general human cognitive architecture is as unlikely as a physiological feature that serves widely disparate anatomical functions:

> 'It is no more probable that some sort of general-purpose brain/mind mechanism could solve all the behavioural problems an organism faces (find food, choose a mate, select a habitat, etc.) than it is that some sort of general-purpose organ could perform all physiological functions (pump blood, digest food, nourish an embryo, etc.)...' (1992: 142)

Evolutionary Psychologists therefore see a direct relationship between specific adaptive problems (domains) and the psychological mechanisms that have evolved to solve the information-processing problems they present. As Buss notes, Evolutionary Psychologists concede that there may be some overlap, to a greater or lesser degree, between certain domains (1995: 8). However, this is seen to be the exception rather than the rule; as a result, Evolutionary Psychologists explicitly reject the view that the human cognitive architecture will be composed primarily of domain-general mechanisms (Ibid).

The second consequence of the view that the psychological mechanisms that comprise the human cognitive architecture are adaptations shaped by natural selection is that they will display species-typicality. Tooby and Cosmides make the point as follows:

> 'Significantly, in species like humans, genetic processes ensure that complex adaptations virtually always are species-typical (unlike nonfunctional aspects of the system). This means that *functional* aspects of the architecture will tend to be universal at the genetic level, even though their expression may often be age or sex limited, or environmentally contingent.' (Tooby & Cosmides, 1990a, cited in Tooby & Cosmides, 2006: 179)

On this view, therefore, there must be a level at which the adaptations that comprise the human psychological architecture are typical to the human species in much the same way that physiological adaptations are typical (for example, a stomach that digests food, a heart that pumps blood etc.). For Evolutionary Psychologists, differences in behaviour are therefore due to a cognitive architecture that is functionally species-typical producing different outputs in response to different environmental inputs.

2.4. The Environment of Evolutionary Adaptedness

Evolutionary Psychologists make the further claim that the adaptive problems our psychological mechanisms have been designed to solve must be of a specific kind. Drawing on the work of Williams (1966) and Dawkins (1986), Tooby and Cosmides argue that the design features that our psychological adaptations exhibit must relate to '...the reproduction of an individual and his or her relatives in ancestral environments' (2006: 180). So not just any adaptive problem will suffice; the kinds of behaviour that a psychological mechanism can promote must correlate to the adaptive problems of our ancestral past. Because the evolutionary process is slow, Tooby and Cosmides argue that the more recent episodes of the human past (approximately, after the agricultural revolution) will have played little, or no role is shaping the human cognitive architecture because the time that has elapsed '...is too brief a period to have selected for complex new cognitive programs' (2005: 17).

It is for this reason that, when considering what psychological adaptations may be present in the human cognitive architecture, Evolutionary Psychologists place an emphasis on the environment of evolutionary adaptedness (EEA hereafter). The EEA is often equated with the Pleistocene from between approximately 2-1.7million to 10,000 years ago (Grossman & Kaufman, 2002: 13; Laland & Brown, 2011: 124). This is assumed to be the period that shaped the human genotype, and where humans (together with their hominid ancestors) existed as nomadic hunter-gatherers in savannah environments (Grossman & Kaufman, 2002: 13; Scher & Rauscher, 2003: 12).

However, although the EEA is often seen to be synonymous with the Pleistocene, it is not identified as a specific place or time:

> 'Although the hominid line is thought to have originated on edges of the African savannahs, the EEA is not a particular place or time. The EEA for a given adaptation is the statistical composite of the enduring selection pressures or cause-and-effect relationships that pushed the alleles underlying an adaptation systematically upward in frequency until they became species-typical or reached a frequency-dependent equilibrium...' (Tooby & Cosmides, 2005: 22)

In this sense, the EEA refers to manifold past environments; for each functionally isolable psychological mechanism in the human cognitive architecture, there are thought to be a corresponding set of selection pressures that constitute the EEA of that particular mechanism. In addition, it is possible that the selection pressures for a given psychological mechanism will be unique to that mechanism: as Tooby and Cosmides state, '...the EEA for one adaptation may be somewhat different from the EEA for another' (2005: 22). So, for example, the EEA for language and the EEA for male provisioning of offspring will be very different both in terms of information-processing problems involved and the chronological depth. Different adaptations will therefore have different depths in terms of evolutionary history (extending to well before the Pleistocene in the case of vision), and different informational content in terms of the facets of the environment with which they were designed to interact.

The importance of the EEA concept to Evolutionary Psychology can be summarised in two main points. Firstly, it highlights a new direction when considering the study of human behaviour and provides a basis for challenging an assumption held by many in the field of Sociobiology, where human beings are viewed as ‘fitness maximisers’ (Buss, 1995: 10; Scher & Rauscher, 2003: 8)

If, as the EEA concept suggests, our brains are adapted to ancestral environments, then human behaviour in modern environments need not always ‘maximise fitness’. In other words, we would fully expect to see maladaptive behaviour in certain instances. Symons, for example, makes a distinction between what is ‘adaptive’ and ‘adaptiveness’. He claims that those who view humans as ‘fitness maximisers’ are examining the latter by searching for adaptations that increase fitness in current environments (1992: 148). In contrast, when considering what is ‘adaptive’, there is no reason to assume it will produce beneficial effects on fitness in current environments.

Each adaptation present in the human cognitive architecture is seen as being closely attuned to the background conditions that prevailed in its EEA. If those background conditions are not met (i.e. if the informational environment changes to the extent that it no longer resembles the EEA of the adaptation) then there are no guarantees it will continue to function as a efficient solution to a given problem (Tooby & Cosmides, 2005: 22). An often quoted example of an adaptation from the EEA that is currently maladaptive is the human sweet tooth, which would have been advantageous for ensuring the consumption of the most nutritious food in ancestral environments, but can motivate an unhealthy diet in a modern population where sugar is abundantly available (Symons, 1992: 139).

The second point to make regarding the importance of the EEA concept is that it provides a framework for generating hypotheses and guiding research. For Tooby and Cosmides, the psychological adaptations that comprise the human cognitive architecture reflect the structure of the EEA (2005: 22). Ascertaining the kinds of adaptive problems present in the EEA therefore represents a crucial step to predicting the functional properties that a proposed psychological mechanisms would require in order to solve the problem (Laland & Brown, 2011: 111).

2.5. The Methodology of Evolutionary Psychology

Given the claims outlined above, Tooby and Cosmides propose a methodology consisting of six steps that will '...allow the principled investigation of the innate mechanisms of the human psyche' (1989: 40, 2005: 28).

The first step is to identify an adaptive problem that would have been present in the EEA (Tooby & Cosmides, 2005: 28). This includes establishing the '...recurrent environmental features relevant to the adaptive problem, including constraints and relationships that existed in the social, ecological, genetic, and physical situation of early hominids...' (Tooby & Cosmides, 1989: 40). An important part of this step is to establish the environmental informational resources that were available for solving the problem in Pleistocene conditions, because a psychological mechanism can only evolve to produce adaptive behaviour in response to such information (Tooby & Cosmides, 1989: 40-41).

The second step is to perform a 'task analysis' for the adaptive problem identified in the first step. This involves establishing the kinds of computations that would need to be performed, with an emphasis on '...what would count as a well-designed program given the adaptive function under consideration' (Tooby & Cosmides, 2005: 28).

For the third step, one formulates a testable hypothesis relating to the kind of programme (or programmes) that could have evolved to perform the kinds of computations outlined in the task analysis in step two (Ibid). This involves developing a 'computational theory' regarding the information-processing problem in question, where the specific informational problems that need to be solved in order for the adaptive function to be realised are catalogued (Cosmides & Tooby, 1987: 287; Tooby & Cosmides, 1989: 41).

The fourth step is to devise experiments to test for the presence of the hypothesised mechanism experimentally. To achieve this Tooby and Cosmides suggest that a wide range of methods can be employed, most notably, from '...cognitive, social, and developmental psychology, cognitive neuroscience/neuropsychology, experimental economics, cross-cultural studies—whatever methods are most appropriate for illuminating programs with the hypothesized properties' (Tooby & Cosmides, 2005: 28).

Where the predicted design features are confirmed empirically, Tooby and Cosmides suggest that the fifth step involves devising and conducting further tests to ensure that alternative hypotheses regarding the design features do not provide a better explanation of the empirical results (2005: 28). The overall aim of these first five steps is to produce '...a validated model of the cognitive programs in question, together with a model of what environmental information, and other factors, these programs take as input' (Tooby & Cosmides, 1989: 41).

Finally, the sixth step involves establishing whether or not the hypothesised psychological mechanism is distributed cross culturally. Though the psychological adaptations that make up the human cognitive architecture are assumed to be species-typical, this need not always result in a uniform trend in terms of the behaviour produced. As Tooby and Cosmides note, different behavioural outputs can be triggered from different environmental cues or social conditions, or otherwise affected by circumstances specific to a given locale (2005: 28). However, where a validated model of the cognitive programme in question has been developed with necessary rigour, Tooby and Cosmides note that it should be possible to predict what manifest behaviour will be apparent in modern environments (1989: 41).

2.6. Criticisms of Evolutionary Psychology

Evolutionary psychology has attracted considerable criticism from various quarters. Below, I will consider criticisms that focus on issues of testability ('just so' storytelling), on adaptationism, on domain-specificity, and the EEA concept. Alongside these, it should be noted that criticisms that misrepresent the work of Evolutionary Psychologists are commonplace, to the extent that Laland and Brown note that there is a 'market niche' for criticisms where '…hostile detractors queue up to heap scorn on a 'straw man' caricature of the field' (2011: 124). Criticisms of this kind typically make unfounded charges of genetic determinism and panadaptationism, or else question the ethics of the field, citing underlying political motivations of the research undertaken. For a good example of this type of criticism see Rose and Rose's edited volume (2000), together with Kurzban's succinct rebuttal (Kurzban, 2002).

2.6.1. Just so Storytelling

A common criticism levelled at Evolutionary Psychology stemming directly from its advocacy of adaptationism is that it amounts to little more than 'just-so' storytelling. Critics adopting this line argue that Evolutionary Psychologists hypothesise uncritically about the selection pressures and adaptive benefits that contributed to the emergence of a given trait (hence the reference to Kipling's 'Just So' stories) (Smith, Borgerhoff Mulder, & Hill, 2001).

Evolutionary Psychologists use both forward and reverse engineering to generate hypotheses (Buss, 1995, 1999), but both methods have been subjected to accusations of just-so storytelling. Critics of the use of forward engineering argue that Evolutionary Psychologists engage in speculation about adaptations that arose during an unknowable Pleistocene past (Buller, 2005a). Regarding reverse engineering, critics argue that Evolutionary Psychologists simply devise a plausible adaptive story for a known psychological capacity (Richardson, 2007), thereby engaging in a form of naïve adaptationism which has previous been the subject of a wider critique within the field of evolutionary biology (Gould & Lewontin, 1979).

The degree to which such accusations are justified depends, to a large extent, on how thoroughly individual researchers adhere to the methodology of Evolutionary Psychology. As noted above, Tooby and Cosmides present a rigorous methodology of hypothesis formulation, testing, and re-testing to eliminate rival explanations for the observed data (1992). Most notably, the fifth step of the methodology calls for a second stage of testing to ensure that alternative hypotheses regarding the design features do not provide a better explanation of the empirical results (2005: 28). However, though the methodology of

Evolutionary Psychology incorporates safeguards against naïve post-hoc storytelling, individual researchers may make errors in its application. Indeed, Tooby and Cosmides anticipate this problem in an early paper, where they note that the temptation to skip steps in the methodology should be resisted (1989: 41).

The accusation that Evolutionary Psychologists attribute adaptive explanations to known psychological traits is also difficult to sustain where research predicts and documents novel psychological traits. Machery, for example, argues that Evolutionary Psychology produces novel results either by testing hypotheses that predict some unknown psychological trait, or by predicting additional, undocumented properties for a known trait (Machery, forthcoming). Indeed, even Buller, who criticises the use of forward engineering in Evolutionary Psychology, acknowledges the legitimacy of using adaptive reasoning to generate hypotheses, particularly where previously undiscovered traits are discovered (2005a: 91).

2.6.2. Alternative Evolutionary Processes

A further related criticism stemming from the emphasis that Evolutionary Psychologists place on adaptationism concerns the central role that Tooby and Cosmides attribute to adaptations. Though they acknowledge that 'by-products' and 'noise' also contribute to the recurrent design of organisms, they stress the central role of adaptation in creating functional organisation (Tooby & Cosmides, 2005: 25-26). Critics, however, argue that numerous additional factors need to be taken into account when considering evolutionary processes, such as niche construction, mutation, recombination, and multi-level selection (Laland & Brown, 2011: 131), as well as genetic drift, pleiotropy, epistasis, spandrels, exaptations, developmental constraints and phenotypic integration (Gray, Heaney, & Fairhall, 2003: 249). Indeed, some have argued that the focus on adaptationism in Evolutionary Psychology circumvents the 'complexities of evolutionary biology' (Laland & Brown, 2011: 133). Laland and Brown summarise the critique succinctly as follows:

> 'If evolution is a complex multi-faceted phenomenon, if many evolutionary processes including drift and mutation are operating at the same time, if evolutionary history is important, if selection is operating at different levels, if evolutionary rates can sometimes be fast, and if evolutionary theory is rapidly developing, it makes the business of predicting and interpreting psychological adaptations more difficult.' (2011: 136)

Evolutionary Psychologists respond to this criticism by arguing that critics have conflated the various levels of study on which researchers operating in various evolution-oriented fields are focused. Processes such as pleiotropy and epistasis, for example, are phenomena studied at the genetic level, whereas Evolutionary Psychology explicitly focuses on studying human behaviour at the macro-level (Ellis & Ketelaar, 2002). In this sense, the study of psychological mechanisms does not require any direct reference to the complex genetic processes involved (Ellis & Ketelaar, 2002: 158). Ellis and Ketelaar argue that criticising Evolutionary Psychology for not incorporating such processes in their research '…is a bit like criticizing the authors of a book on how to play billiards as having neglected to discuss quantum mechanics as the "real foundation" of the field of billiards.' (2002: 158).

At the other end of the scale, Ellis and Ketelaar respond to criticism that Evolutionary Psychologists neglect to consider multi-level selection theories by arguing that it is too premature to suggest that such models should replace 'the standard, gene-centred adaptationist program' (2002: 158). For them, 'multilevel selection models and gene–

culture coevolution models have (thus far) proven scientifically barren as tools of discovery' (Ellis & Ketelaar, 2002: 158).

2.6.3. Domain-General Learning

Another aspect of Evolutionary Psychology that has attracted criticism is its commitment to domain specificity and the massive modularity of the human cognitive architecture (Tooby & Cosmides, 1992). The massive modularity hypothesis proposes that the human cognitive architecture consists of a large number of 'Darwinian Modules', each of which is dedicated to solving an adaptive problem in past environments (Machery, 2007: 827). For Evolutionary Psychologists, massive modularity is the most feasible model for the human cognitive architecture for reasons of optimality (i.e., psychological mechanism specifically attuned to solve a given problem will outperform a more general-purpose mechanism, and are therefore more likely to be a product of natural selection) and also solvability (i.e., a domain-general human cognitive architecture is deemed inadequate for solving the vast array of adaptive problems encountered in Pleistocene environments which, again, would result in selection for domain-specific structures) (Samuels, 2000: 30, 35).

In contrast, critics contend that many psychological traits may in fact be domain-general, that such structures are no less compatible with evolutionary theory, and that structures capable of problem-solving in various domains would represent a low cost solution to various adaptive problems:

> 'A rule such as 'actions that are followed by a positive outcome are likely to be repeated, while those followed by a negative outcome will be eliminated' is domain-general in the sense that it can be

> equally applied to behaviour concerned with finding food, avoiding predators, or seeking a mate.' (Laland & Brown, 2011: 129)

Tooby and Cosmides respond to this criticism by arguing even apparent domain-general learning capabilities require underpinning by evolved mechanisms:

> '…classical and operant conditioning are widely viewed as the simplest and most general forms of learning in humans and other animals. Yet, even operant conditioning presumes the existence of evolved mechanisms that change the probability of a behaviour by a certain amount, as a function of its consequences (and according to very precise equations). It also presumes that a handful of consequences—food, water, pain—are "intrinsically" reinforcing (i.e., the fact that these consequences are capable of changing the probability of a subsequent behaviour is a design feature of the brain). Classical conditioning presumes the existence of a great deal of evolved equipment. In addition to the programs that compute contingencies, the animal is filled with unconditioned— that is, unlearned—responses, such as salivating in response to meat.' (Tooby & Cosmides, 2005: 31 - emphasis in original).

Others, such as Barrett, argue that the question of whether the human cognitive architecture is more domain-general or domain-specific is an empirical one that remains open to dispute, and that the answer will only be found through further research into the problem-solving capabilities of the human brain:

> 'By "domain general," most psychologists are referring to mechanisms that can be applied to a wide range of problems. In this sense, domain-general adaptations clearly exist, and the mind is therefore a mixture of domain-specific and domain-general mechanisms. However, even on this construal of domain generality, the question of just "how specialized" or "how generalized" the mind is overall is

> an empirical question that we still don't have the answer to, because the work of discovering and describing all of the mind's mechanisms is not yet done.' (Barrett, 2009: 104)

Interestingly, stone tool production potentially represents an area where empirical research from the perspective of Evolutionary Psychology is lacking. Chapter 2 explores this issue in depth, arguing that current research into stone tool production pre-supposes a reliance on domain-general capacity for acquiring the associated skills.

2.6.4. Criticism of The EEA Concept

The concept of the EEA rests on two main assumptions that have been the focus of criticism. The first assumption stems from the fact that psychological mechanisms are viewed as the product of an evolutionary process, and would therefore have developed slowly. As a result, it is assumed that no significant change is likely to have occurred in the human biological makeup (including our psychological mechanisms) since the posited end of the EEA (i.e. after approximately 10,000 years ago) (Grossman and Kaufman 2002: 13). However, the view that no meaningful changes have occurred regarding our psychological architecture since the Pleistocene is highly disputed (Laland & Brown, 2002: 180-181). Indeed, Irons cites two examples of physiological adaptations that have emerged since the end of the Pleistocene: *viz*, the production of lactase in adulthood and the sickle-cell trait (1998: 195). Though Tooby and Cosmides view these examples as ' minor exceptions' (1990b: 388), the prospect of novel psychological traits developing within such a timeframe remains plausible.

Secondly, there is the assumption that the EEA is sufficiently 'knowable' to do the conceptual work that is required. Proponents of Evolutionary Psychology suggest that knowing the ancestral conditions under which a species evolved can suggest hypotheses about the design features of the cognitive adaptations that solve a given problem (Tooby and Cosmides 1992: 68). However, in many cases it is questionable whether the specifics of ancestral conditions can be 'known' in sufficient detail. Indeed, Laland and Brown suggest that the paucity of information relating to ancestral conditions has led to instances of '...undisciplined speculation and story-telling in which virtually any attribute can be regarded as an adaptation to a bygone Stone-Age world.' (2002: 177).

Furthermore, the homogeneity implied by the use of the term 'Pleistocene hunter-gatherer environments' without further elucidation is itself problematic. As Irons notes, this creates '…a false picture of stasis during this period' because no single hunter-gatherer lifestyle was adopted following emergence of modern *Homo sapiens*; instead, there are a variety of hunting and gathering lifestyles, each with its own distinct nuances and challenges (Irons, 1998: 195).

Any adaptive trait viewed as 'typical' of hunter-gatherers should therefore be viewed with caution. Foley (1995) for example, emphasises this point by collating evidence from ethnographic studies that highlight the variety exhibited by hunter-gatherer groups in areas such as group size (which ranges from 9-1500 individuals) (Hayden, 1981, cited in Foley 1996, p.195), male contribution to diet (ranging from 20% to 100%) (Hiatt, 1970, cited in Foley 1996, p.195), and group mobility (ranging from fully sedentary to moving as frequently as fifty times in a year) (Kelly, 1983, cited in Foley 1996, p.195).

In response to the above criticism, proponents of Evolutionary Psychology point out that, though it is true that many aspects of the EEA are unknowable, and that hunter-gather lifestyles may be varied, there are many aspects of humanity's evolutionary past for which we can examine the prevailing selection pressures with a high degree of confidence (e.g., the risks involved in pregnancy, high infant mortality, disease/parasites/other dangers present, the kin-based nature of tribal groups, the problems associated with other humans being both co-operators and competitors) (Rossano, 2003: 46). Finally, one could argue that the methodology of Evolutionary Psychology includes certain safeguards against the undisciplined use of the EEA concept. This is because the hypotheses that guide test design and data collection are initially formulated with reference to the EEA. One could therefore surmise that badly formulated characterisations of a given adaptive problem will predominantly result in hypotheses that will not be supported by the data.

2.7. Case Studies

As a field of research, Evolutionary Psychology covers an eclectic range of subject areas focusing on various aspects of human cognition and behaviour. Some of the most prominent research examines the subject of cognitive adaptations for social exchange (i.e., reciprocation, reciprocal altruism, cooperation) (Cosmides, 1989; Cosmides & Tooby, 1989, 1992, 2000a, 2004, 2005; Gigerenzer & Hug, 1992; Platt & Griggs, 1993; Sugiyama, Tooby, & Cosmides, 2002), as well as various aspects of human sexuality (Buss, 1994), including male mate choice (Singh, 1993; Sugiyama, 2005), female mate choice (Buss, 1989; Buss & Schmitt, 1993), mutual mate choice (Buss & Barnes, 1986), romantic jealousy (Buss, Larsen, & Westen, 1992; Daly, Wilson, & Weghorst, 1982), male same-sex conflict in mate choice (Daly & Wilson, 1988; Wilson & Daly, 2004), female same-sex conflict in mate choice (Buss & Dedden, 1990; Symons, 1979), and coercion (Buss & Shackelford, 1997; Gallup & Chavanne, 2003; Thornhill & Thornhill, 1989). One area in which the contribution of Evolutionary Psychology has been much lauded is that of child abuse, where the work of Daly and Wilson provided such robust evidence for increased risk of abuse where a step-parent is present in the home that it has contributed to policy development in youth services (Confer, et al., 2010: 121; Daly & Wilson, 2005; Herring, 2009).

Other areas covered by Evolutionary Psychology include homicide (Daly and Wilson 1988), spatial location (New, Krasnow, Truxaw, & Gaulin, 2007; Silverman & Eals, 1992), predator avoidance (Barrett, 2005; Barrett & Broesch, 2012), disgust (Curtis, Aunger, & Rabie, 2004; Fessler & Haley, 2006; Fessler & Navarrette, 2003; Nesse & Williams, 1995), depression (Andrews & Thomson, 2009; Keller & Nesse, 2006), memory (Klein, Cosmides, Gangi, Jackson, & Tooby, 2009), emotion (Cosmides & Tooby, 2000b), and sibling kin-detection (Lieberman, Tooby, & Cosmides, 2007).

Though a combination of the vastness of the existing literature and limitations of space prevent a detailed examination of the field of Evolutionary Psychology as a whole, below I will consider two case studies in detail, one of which represents a robust application of the methodology of Evolutionary Psychology (Cosmides studies into the logic of social exchange), and one which suffers from some of the weaknesses highlighted by critics (Fessler's study on fire learning).

2.7.1. Cosmides: The Logic of Social Exchange

In a seminal paper, Cosmides examined whether the human cognitive architecture contains specialised psychological mechanisms for detecting cheaters (Cosmides, 1989). Her work was based on the general premise that within a social group where reciprocal altruism plays an important role, being cognitively attuned to detect cheats should bestow an advantage by facilitating the detection of individuals who benefit from social exchanges without incurring any of the accompanying cost (Barrett, Dunbar, & Lycett, 2002: 281; Laland & Brown, 2011: 113-114).

This approach was in contrast to the existing assumption of researchers in the social and behavioural science (see, for example, Cheng & Holyoak, 1985; Sperber, Cara, & Girotto, 1995) that humans have a ‘powerful, general cognitive capacity (intelligence, rationality, learning, instrumental reasoning)’ that accounts for most of human behaviour (often referred to as ‘the blank slate’ or standard social science model) (Cosmides & Tooby, 2005: 585; Tooby & Cosmides, 1992).

Cosmides work built on previous findings by Wason (1966), who found that that the ability of human test subjects to reason well in selection tasks incorporating a conditional rule (i.e., if P then Q) was contingent on the subject matter used (Laland & Brown, 2011: 115). Cosmides posited that adopting an evolutionary perspective could provide an explanation for the evident discrepancies in how well people reasoned in different contexts. She therefore devised a series of tests to examine ‘the hypothesis that the enduring presence of social exchange interactions among our ancestors has selected for cognitive mechanisms that are specialized for reasoning about social exchange’ (Cosmides & Tooby, 2005: 585).

One of the particular strengths of Cosmides work is that it applies the methodology of Evolutionary Psychology in a rigorous way, for example in conducting a thorough task analysis of the problem under consideration, predicting design features based on the task analysis, and in providing a detailed consideration of alternative explanations for the data (Cosmides & Tooby, 1992, 2005). Based on the task analysis, and prior to any testing, the following series of six design features were predicted for the proposed mechanism:

1. Since social exchanged is defined as cooperation for mutual benefit, the proposed mechanism will only be triggered where obligations/entitlements appropriate to social contacts are present.
2. Since cheating represents a way of violating a social contract, a system designed for cheater detection will only be triggered where the rules specify a benefit for any violators.
3. The definition of cheating is dependent on the perspective of the agent, so the proposed mechanism needs to be able to judge cost/benefits from different perspectives and define cheating accordingly.
4. A powerful response should be elicited in instances where intentional cheating is detected, whereas mistakes that result in an individual being cheated should produce a weak response, or no response at all.
5. The posited mechanism should be able to recognise/reason about social exchange regardless of how unfamiliar the context – new exchange contexts should therefore still elicit a high level of cheater detection.
6. Though the posited mechanism should operate well for reasoning about social contracts, it need not do the same for contexts involving content-free, formal logic (Cosmides & Tooby, 2005: 593).

Given the above predictions, Cosmides set out to produce design evidence that the posited social exchange mechanism solves the problems associated with the adaptive problem in 'a well-engineered way' (Cosmides & Tooby, 2005: 590). The first test that Cosmides conducted aimed to compare how well test participants reasoned in a context where some form of social contract was present and in one where it was lacking. Figure 2.1 shows an example of a Wason selection task that does not include a social contract.

Ebbinghaus disease was recently identified and is not yet well understood. So an international committee of physicians who have experience with this disease were assembled. Their goal was to characterize the symptoms, and develop surefire ways of diagnosing it.

Patients afflicted with Ebbinghaus disease have many different symptoms: nose bleeds, headaches, ringing in the ears, and others. Diagnosing it is difficult because a patient may have the disease, yet not manifest all of the symptoms. Dr. Buchner, an expert on the disease, said that the following rule holds:

"If a person has Ebbinghaus disease, then that person will be forgetful."
If P then Q

Dr. Buchner may be wrong, however. You are interested in seeing whether there are any patients whose symptoms violate this rule.

The cards below represent four patients in your hospital. Each card represents one patient. One side of the card tells whether or not the patient has Ebbinghaus disease, and the other side tells whether or not that patient is forgetful.

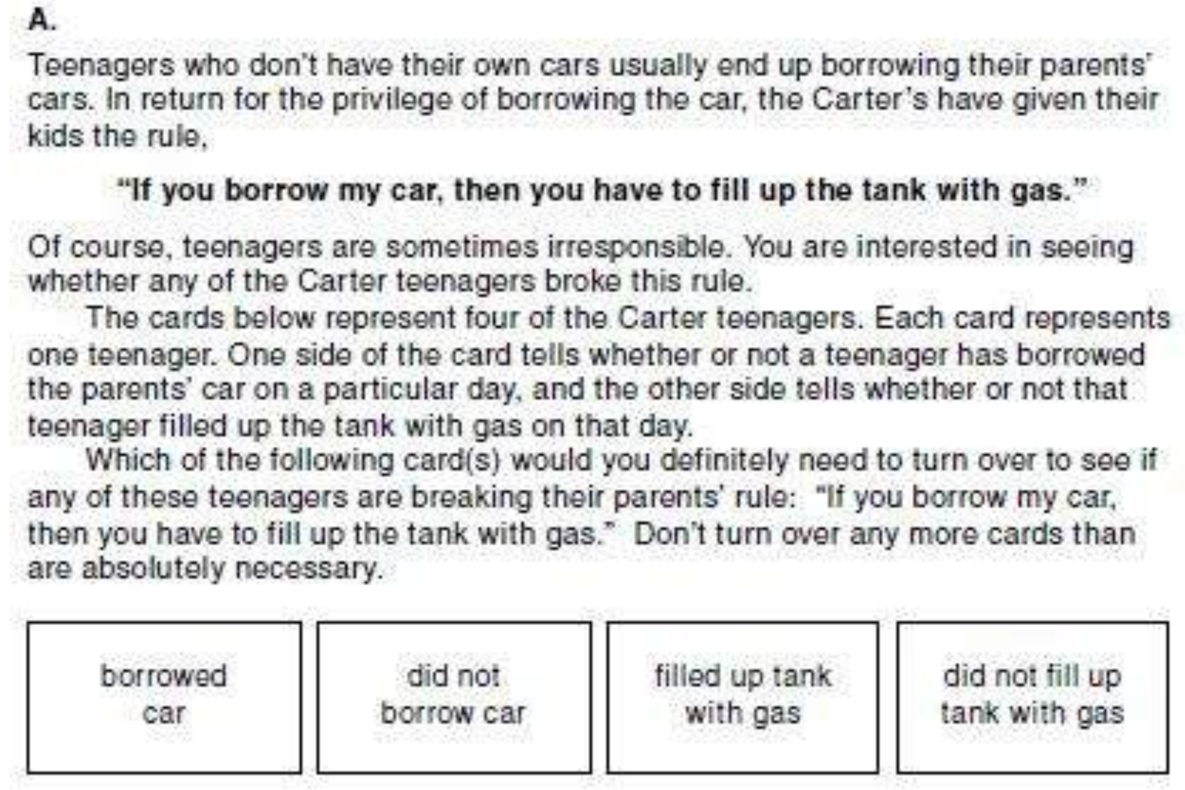
Which of the following card(s) would you definitely need to turn over to see if any of these cases violate Dr. Buchner's rule: "If a person has Ebbinghaus disease, then that person will be forgetful." Don't turn over any more cards than are absolutely necessary.

has Ebbinghaus disease	does not have Ebbinghaus disease	is forgetful	is not forgetful
P	*not-P*	*Q*	*not-Q*

Figure 2.1: An example of a Wason Selection Task. The Wason selection task asks test subjects to correctly interpret the logical rule of the form '*If P then Q*'. Given the context of the task outlined above, test subjects make a decision as to which of the four cards at the bottom need to be turned over to ensure the rule is upheld. As outlined above, the content of the cards on the visible side correspond to *P*, *not-P*, *Q*, and *not-Q*. The only combination that can contravene the rule is if a card has *P* on one side and *not-Q* on the other. To successfully complete the task, therefore, test subjects must select the *P* card (to see if it has *not-Q* on the reverse), the *not-Q* card (to see if it has *P* on the reverse), but no others. Note that the italicized sections beneath the cards and the rule (in bold) are for explanatory purposes only, and are not seen by test participants (Cosmides & Tooby, 2005: 595).

Despite containing terms that are familiar with everyday life (rather than presenting the problem in a purely logical form) as many as 70% to 95% of people tested failed to provide the correct response (Cosmides & Tooby, 2005: 595-596). In contrast, when test subjects were presented with a task that incorporated a form of social contract, as in Figure 2.2, while retaining the same inherent logic as Figure 2.1, their performance improved significantly:

> 'Whenever the content of a problem asks one to look for cheaters in a social exchange, subjects experience the problem as simple to solve, and their performance jumps dramatically. In general, 65% to 80% of subjects get it right, the highest performance found for a task of this kind.' (Cosmides & Tooby, 2005: 596)



A.

Teenagers who don't have their own cars usually end up borrowing their parents' cars. In return for the privilege of borrowing the car, the Carter's have given their kids the rule,

"If you borrow my car, then you have to fill up the tank with gas."

Of course, teenagers are sometimes irresponsible. You are interested in seeing whether any of the Carter teenagers broke this rule.

The cards below represent four of the Carter teenagers. Each card represents one teenager. One side of the card tells whether or not a teenager has borrowed the parents' car on a particular day, and the other side tells whether or not that teenager filled up the tank with gas on that day.

Which of the following card(s) would you definitely need to turn over to see if any of these teenagers are breaking their parents' rule: "If you borrow my car, then you have to fill up the tank with gas." Don't turn over any more cards than are absolutely necessary.

borrowed car	did not borrow car	filled up tank with gas	did not fill up tank with gas

Figure 2.2: A Wason selection task that includes a Social Contract Rule. In this case, the test subjects need to turn over 'borrowed car' (*P*) and 'did not fill up the tank with gas (*not-Q*), but no others in order to make sure the rule has not been contravened. Though the inherent logic in the task above is identical to Figure 2.1, test subjects perform remarkably better when the task incorporates a form of social contract (after Cosmides & Tooby, 2005: 597).

Furthermore, the same pattern is maintained cross-culturally for test subjects from the 'United States, United Kingdom, Germany, Italy, France, Hong Kong, Japan; schoolchildren in Quito, Ecuador; Shiwiar hunter-horticulturalists in the Ecuadorian Amazon' (Cosmides & Tooby, 2005: 596; Sugiyama, et al., 2002). Cosmides and Tooby argue that such results provide good initial evidence that the human cognitive architecture contains reasoning procedures that are attuned to the problem of cheater detection in social exchange situations (Cosmides & Tooby, 2005: 596; Tooby & Cosmides, 1997).

As noted above, one of the strengths of Cosmides work is that subsequent tests were conducted in order to further eliminate rival hypotheses. For example, one may posit that the patterns evident from the tests described above may be due to the fact that the situations used in the Wason selection task incorporating a form of social contract are simply more familiar to the test subjects, and that this can account for the discrepancies in performance.

Cosmides addressed the problem of familiarity by manipulating the content of the test, while retaining the same underlying logic, to include a 'culturally alien rule'- in this case 'If a man eats cassava root, then he must have a tattoo on his face' (Cosmides, 1989; Cosmides & Tooby, 2005: 599; Gigerenzer & Hug, 1992). This form of test was replicated with a number of variations on different unfamiliar rule types, and the same high level of performance in contexts where cheater detection was involved (Cosmides & Tooby, 2005: 599). Indeed, the reverse case produces the same pattern: when the task is conducted with culturally unfamiliar content in the absence of a social exchange context (as in Figure 2.1), a low success rate was once again evident.

In a third test, Cosmides and Tooby switched the order of the conditional rule so that the logically correct answer to the task conflicted with the correct answer according to social contract theory (Cosmides & Tooby, 1992: 187-190) (see Figure 2.3).

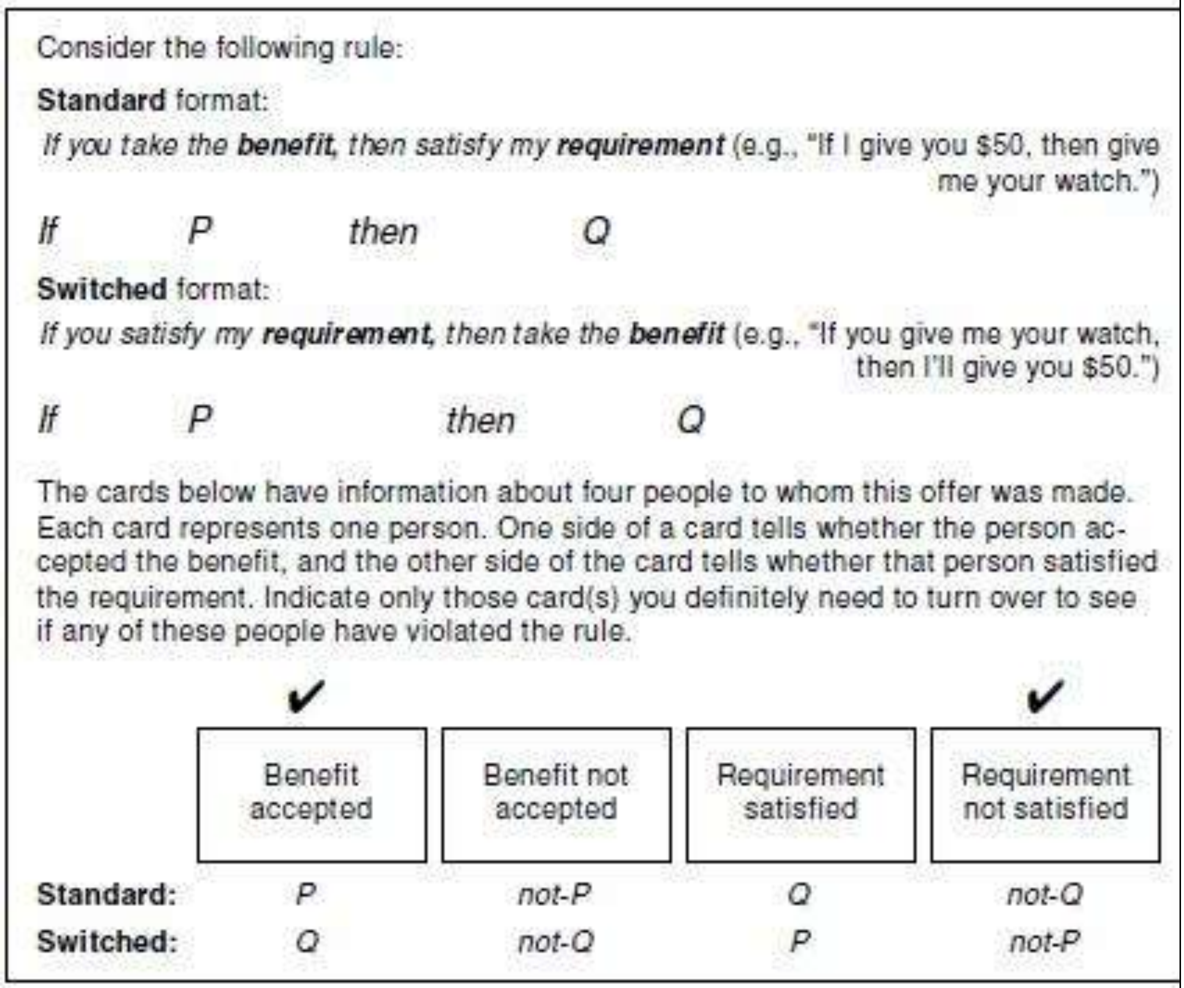


Figure 2.3: Generic structure of a Wason selection task with standard and switch content. A Wason selection task incorporating social contract information can be translated in terms of its logical content (If *P* then *Q*) or its social contract content (requirements and benefits). The Figure above demonstrates how it is possible to reverse the order of the social contract content, meaning that the correct answer in terms of requirements/benefits is logically incorrect. Tests adopting this generic structure can be used to demonstrate that reasoning procedures hone in on information relating to cheaters, as opposed to logical content (after Cosmides & Tooby, 2005: 601).

The motivation for this test was to examine whether social contract content simply facilitates logical reasoning abilities, thereby raising the prospect that the former is a by-product of the latter (Barrett, et al., 2002: 281, 283; Cosmides & Tooby, 1992: 187). The test design exploits the fact that in formal logic, *If P then Q* does not imply *If Q then P* (e.g., ‘It’s a dog, therefore it has a nose’ does not imply ‘It has a nose, therefore it’s a dog’).

Interestingly, this relationship does not translate to requirement/benefit situations – i.e., the inferential rules of social exchange allow ‘If you take the benefit (*P*), then you are obligated to satisfy the requirement (*Q*)’ to be switched to ‘If you satisfy the requirement (*Q*), you take the benefit (*P*)’. As a result, it becomes conceivably to devise selection tasks adopting the generic structure illustrated in Figure 2.3, where test subjects must make a choice between providing the correct answer for the social contract content or the logical content. The results from these tests indicate that the subjects overwhelmingly reject the logically correct answer, instead providing the answer that correctly detects cheaters (Cosmides & Tooby, 2005: 602).

Perhaps the most prominent criticisms of the studies cited above focus on methodological issues regarding the validity of the use of the Wason selection task. For example, both Buller (2005b) and Fodor (2000) have argued that there are structural disanalogies exist between the logical forms used in the Wason selection tasks employed by Cosmides and Tooby. Buller argues that all conditionals do not have same logical form, and the different forms invoked in the selection tasks used can explain differences in performance: ‘the so-called content effect is typically induced by pairing ‘indicative conditionals’ with ‘deontic conditionals’ in selection tasks. But these have different logical forms and warrant different patterns of inference’ (Buller, 2005b: 279).

Cosmides and Tooby rebut this claim by arguing that, if it were true, one could make the following prediction: '… good performance (high levels of violation detection) will be found across a broad range of deontic rules, rather than just among the narrower subsets of deontic rules, like social contracts and precautions, that were evolutionarily significant' (Cosmides, Tooby, Fiddick, & Bryant, 2005: 505). This, they claim, with reference to the studies cited above, is 'demonstrably false' (Cosmides, et al., 2005: 505).

Further, they point to studies designed to examine differences in performance where intentional or accidental cheating occurs (i.e., to test design feature 4 noted above). In such studies, identical social contracts, with the same deontic logical form, elicited a high level of performance for intentional cheating but poor performance when cheating could be interpreted as accidental (Cosmides, Barrett, & Tooby, 2010; Cosmides & Tooby, 2000a; Fiddick, 2004). Arguably, if Buller's criticism were valid, identical social contracts with identical logical content should elicit equivalent performance (either high or low), but the results suggest they do not (Cosmides, et al., 2005: 505).

In summary, the studies cited above provide strong evidence supporitng the hypothesis that humans reason more effectively in social contract situations. Cosmides and Tooby's research examining possible adaptive specialisations for social exchange represents some of the strongest research in the field, comprising a rigorous application of the methodology of Evolutionary Psychology, including repeated and astute redesigns of the test format in order to target the assumptions inherent in rival explanations. Indeed, even critics of the field acknowledge the merit of the studies described above, particularly noting the clear predictions generated and the novel insights evident in the data (Gray, et al., 2003: 261).

2.7.2. Fessler: An Evolutionary Psychology of Fire Learning

Alongside studies that adopt a rigorous methodology, the field of Evolutionary Psychology has, as Laland and Brown note, produced a number of 'weak studies and unsupported narratives' (2011: 123). I would argue that Fessler's examination of 'fire learning' falls into this category.

Fessler's main thesis is that a combination of the adaptive benefits of fire use, the inherent dangers of fire use, and the chronologically deep human association with fire, may have led to the evolution of 'psychological mechanisms dedicated to controlling fire' (2006: 429).

Fessler further claims that innate fire management skills in humans must take on a specific form. He rejects the notion that an 'innate template' would be appropriate for the control of fire (akin to that of, say, a spider's web building abilities). This, he argues, is because of the wide range of ecosystems that humans have occupied, which in turn negates any uniformity in the properties of the combustible facets of those ecosystems:

> '...such a template would have been of limited utility, as it would necessarily have been parochial to a given ecosystem due to its reliance on fixed types rather than attributes.' (Fessler, 2006: 431).

Instead, Fessler claims that parallels should exist between a psychological mechanism for fire learning and a psychological mechanism from another domain that deals with 'attributes', rather than fixed types. Drawing on the work of Barrett (2005), Fessler proposes that predator avoidance comprises a domain of this kind (2006: 432).

Fessler makes two main points to support his claim. First, he sees a direct analogy between the high cost of acquiring information about predators and the cost of learning about the combustible properties of various fuels:

> '...generalized, feedback-based learning is inappropriate to the task of acquiring information about predators since, particularly for children, the costs of such learning would be prohibitively high [...] Correspondingly, if children were to acquire their knowledge of fire exclusively through individual trial-and-error learning, a large percentage would suffer serious or fatal burns.' (2006: 432-433).

Secondly, he sees a direct analogy between the problem of identifying and differentiating different fuels and the problem of identifying different predators. Some cues for 'predator' are seen as being shared (e.g. large in size, possessing teeth or claws), but they are not universal (i.e. there will be differences in size, morphology and behaviours) (Fessler, 2006: 432). Combustible elements of the environment are assumed to vary in their properties (their cues) just as predators differ in terms of morphology and behaviour. So, for Fessler, the lack of universal cues for 'fuel' from the environment negates any prospect of an innate template for fuel recognition.

Given the above, Fessler predicts that a psychological mechanism dedicated to fire learning would display five main properties. First, learning would occur without extrinsic motivation, and children will exhibit curiosity regarding the flammability of various materials; secondly, task-relevant information would be acquired rapidly, often from a single exposure; thirdly, socially-transmitted information would be a valuable source of information as low cost 'learning at a distance'; fourthly, the information acquisition system can be expected to employ biases or prior structures that guide learning in the specified domain (for example, the use of simple dichotomies such as 'flammable' verses ‘non-flammable’); finally, the use of play should bolster the acquisition of procedural knowledge by generating relevant experience in a safe context (e.g., making small fires, playing with embers) (2006: 433-434).

To further examine the claims made above, Fessler draws on the existing literature relating to ‘fire play’ for children in modern settings, as well as ethnographic examples of fire use by children where fire is used routinely as a tool. Regarding the former, Fessler’s assessment of the existing literature highlights three main trends: first, that western children first become curious about fire in early childhood; second, that fire play ‘increases as a function of age, often extending well into adolescence’; and third, that some attraction to fire persists into maturity (as evidenced by the value that western adults place on gazing into a fire) (2006: 437-438). Fessler concludes that fire learning in modern societies presents ‘highly distorted portrait of the developmental unfolding of a mechanism aimed at acquiring fire knowledge and skills’ (2006: 438).

To examine this last point in more depth, Fessler draws on his own previous ethnographic observations in Sumatra (which he admits was not primarily concerned with collecting data on how children interact with fire) as well as interviews with 19 ethnographers covering disparate regions (2006: 441). Fessler highlights the following main trends from these sources: children are exposed to fire play at an early stage (between being a toddler and 6 years old); children play with fire in a strictly ‘utilitarian’ way which differs from western children; children more commonly tend fires rather than make them; girls gain competence earlier than boys; the average age of proficiency is 6.5 years (2006: 441).

In his conclusions, Fessler suggests that the modern disconnect between western children and fire as a 'mundane' tool may have ramifications for pedagogy relating to fire safety for children, while also tentatively suggesting the disruption of a fire learning mechanism during development may account for conditions such as pyromania: '...the ontogeny of this condition may epitomize the costs of disrupting the normal trajectory of information-acquisition processes that are guided by evolved mechanisms.'(2006: 448).

Fessler's examination of fire learning from the perspective of Evolutionary Psychology suffers from a number of weaknesses. In the first instance, one could question whether generalized feedback learning is in fact inappropriate for acquiring information about fire use in the way Fessler proposes. Arguably, he draws a false analogy between predator avoidance and fire learning, particularly when characterising the perceived high costs incurred. The fact that the human body is equipped with a pre-existing, unconscious reflex to pull away from sources of external damage (including burns) represents a general purpose means of promoting safe behaviours around fire, though such reflexes would arguably fail promote safe behaviour in the domain of predator avoidance.

Further, Fessler fails to provide any support for the claim that trial and error learning of fire use would lead to a 'large percentage' of children suffering 'serious or fatal burns' (2006: 433). It is equally feasible that a large percentage would suffer only a minor burn and remember the circumstances in which the injury occurred for future reference. Based on his initial assumptions, therefore, one could question whether the selection pressures Fessler envisages are feasible; if they are not then his work mischaracterises the EEA of fire learning.

Further weaknesses in Fessler's study include the weak method of data collection adopted and his failure to consider alternative hypotheses for the data. As stated previously, the fourth step of the methodology of Evolutionary Psychology involves devising experiments to test for the presence of a hypothesised mechanism. The approach Fessler takes to this stage of the methodology is inadequate, and involves no targeted primary data collection. Though his examination of the existing literature on fire learning is thorough, the incorporation of *post hoc* recollections of ethnographic researchers is methodologically flawed.

To take one example, Fessler notes from the existing literature that 'fire gazing' is a common habit for adults in western societies, and subsequently notes a more utilitarian attitude to fire in the ethnographic cases covered. However, due to the fact that none of the ethnographic researchers interviewed explicitly focused on fire learning, one cannot, on the basis of the collected data, reject the prospect of similar behaviours being present in the societies studied (i.e., there may be ethnographic cases where fire is viewed both as utilitarian and as a source of fascination, resulting in behaviours such as fire gazing).

The fifth step of the methodology of Evolutionary Psychology involves devising and conducting further tests to ensure that alternative hypotheses regarding the design features do not provide a better explanation. Fessler's study lacks a serious consideration of any alternatives to the proposed fire learning mechanism. For instance, though he argues that a psychological mechanism dedicated to fire learning would share many of the properties as a mechanism for predator avoidance, he fails to consider that this mechanism may operate as a by-product of existing cognitive structures. Similarly, though he mentions domain-general learning as an alternative to domain-specific learning, he neglects to fully consider the former as an alternative. Indeed, one could argue that none of the five properties that Fessler proposes for a domain-specific fire learning module is necessarily prohibitive to domain-general learning.

2.8. Conclusion

In conclusion, in this chapter I have provided an outline of Tooby and Cosmides conception of Evolutionary Psychology. Firstly, I focused on the concept of the evolved psychological mechanism, which perform an information-processing function are subject to natural selection based on whether the behaviours that they elicit promote fitness (i.e. survival or reproduction).

I then outlined the claim made by Evolutionary Psychologists that the psychological mechanisms that comprise the human brain are adaptations, and that they are identifiable through their complex functional organisation. In addition, I discussed the two main commitments that result from this claim. First, that the presence of numerous and diverse adaptive problems in ancestral environments will have resulted in a human cognitive architecture consisting of many psychological mechanisms that have been shaped by natural selection to operate within a specific domain. Secondly, that the human cognitive architecture will be species-typical at a functional level in much the same was as other physiological adaptations.

I then outlined the EEA concept as conceived by Evolutionary Psychologists. I suggested that the importance of the EEA to Evolutionary Psychology can be summarised in two main points: that the EEA represents the ‘background conditions’ that a given psychological mechanism has evolved to operate within, and that optimal behaviour in modern environments should not be expected where the background conditions differ from those of the EEA. The importance of the EEA concept as a framework for generating hypotheses in Evolutionary Psychology was also emphasised.

I then outlined the six-step methodology of Evolutionary Psychology, which consisted of (1) a characterisation of the EEA for a particular adaptive problem, (2) the completion of a task analysis for the problem under consideration in order to (3) establish the salient information-processing of the proposed mechanism and formulate corresponding testable hypotheses, (4) to devise and conduct initial experiments to test for the presence of the proposed mechanism, (5) conduct further tests to eliminate equally viable candidate models, and (6) to attempt to establish whether the structure is reliably observable cross-culturally.

The four main criticism of Evolutionary Psychology, together with rebuttals, were then considered, including issues of testability, neglecting to consider alternative evolutionary processes, domain-general learning, and criticisms of the EEA concept. I argued that some of the criticisms highlighted were wholly justified in such cases where the methodology is not rigorously applied (i.e., testability, use of the EEA concept), but that others were either misguided (i.e., neglecting to consider alternative evolutionary processes) or remain open to dispute (i.e., domain-general learning).

Finally, I considered two case studies: Cosmides and Tooby's research into the logic of social exchange, which I argued represents a meticulous application of the methodology of Evolutionary Psychology, and Fessler's research on fire learning, which I argued suffers from a mischaracterisation of the EEA of fire learning, contains methodological flaws, and also overlooks important steps in the methodology of Evolutionary Psychology.

Chapter 3: Evolutionary Psychology and Cognitive Archaeology

3.1. Introduction

This aim of this chapter is to assess the current state of cognitive archaeology as a discipline, particularly emphasising cognitive approaches to studying stone tool production, in order to determine the prospective areas in which Evolutionary Psychology has the potential to make a distinctive contribution to ongoing research. The chapter is broadly divided into three main sections.

The first section examines the current state of cognitive archaeology, noting that of the two main areas into which the discipline can be divided (i.e., processual-cognitive archaeology and evolutionary-cognitive archaeology), it is the theory, methods and data of the latter that are of primary importance when seeking to apply the methodology of Evolutionary Psychology to stone tool production. A characterisation of evolutionary-cognitive archaeology, including an overview of associated areas of research, is also provided.

The second section focuses on the theoretical frameworks and methodological approaches adopted by researchers in evolutionary-cognitive archaeology. In particular, I focus on characterising two prominent methods that are utilised within evolutionary cognitive archaeology: the 'final product' method and the *chaîne opératoire*. Studies based on both of these methodologies are examined, together with the respective drawbacks associated with each approach. In addition, research conducted from two further perspectives will be considered: those of neuroscience and those concerned with lithic experimentation and replication (though relevant in terms of data, these approaches are not currently considered integral to evolutionary-cognitive archaeology).

The final section of this chapter will consider the possible contributions that Evolutionary Psychology, as conceived by Tooby and Cosmides (Tooby & Cosmides, 1989; Tooby & Cosmides, 1990b; Tooby & Cosmides, 1992, 2005, 2006), could make to our understanding of stone tool production. In particular, I will argue that Evolutionary Psychology holds the prospect of challenging several tacit assumptions on which the current approaches to the study of stone tools are based, of suggesting alternative methods of testing and data collection, and of identifying potentially novel cognitive capacities associated with stone tool production.

3.2. Cognitive Archaeology

Cognitive Archaeology (also referred to as 'archaeology of mind') represents a sub-discipline in archaeology where 'explicit attention is paid to processes of human thought and symbolic behaviour' (Mithen, 1999a: 122). The main challenge of the field centres on inferring various aspects of past thought processes indirectly, and reconstructing them as far as is feasible with reference to the material remains that constitute the archaeological record:

> '… appropriate interpretations of past material culture, the behavioural processes that created it, and long-term patterns of culture change evident from the archaeological record, such as the origin of agriculture and the development of state society, requires that those belief systems and processes of thought be reconstructed.' (Mithen, 1999a: 122)

Though applying differing terminologies, both Mithen (1999a) and Nowell (2001) argue that cognitive archaeology can be broadly delineated into two distinct areas of research, both in terms of the time-frames addressed by each and in terms of the overall aims (Preucel, 2006: 148)[4].

The first of these, referred to as 'cognitive-processual' archaeology (Mithen, 1999a: 122; Renfrew, 1994: 9), concerns contexts from the Neolithic up to the most modern (Nowell, 2001: 20)[5]. Proponents of this approach such as Flannery and Marcus, for example, offer this definition:

> 'Cognitive archaeology is the study of all those aspects of ancient culture that are the product of the human mind: the perception, description, and classification of the universe (cosmology); the nature of the supernatural (religion); the principles, philosophies, ethics, and values by which human societies are governed (ideology); the ways in which aspects of the world, the supernatural, or human values are conveyed in art (iconography); and all other forms of human intellectual and symbolic behaviour that survive in the archaeological record.' (1996: 351)

Note that the emphasis here is very much on the human mind and human societies, and the religion, iconography and ideology that they produce (Mithen, 1999a: 122; Nowell, 2001: 22). For present purposes, this area of cognitive archaeology will not be considered further due to the fact that, for the most part, the data focused on are not germane to the task of applying the methodology of Evolutionary Psychology to stone tool production[6].

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[4] A third, post-processual cognitive approach to archaeology can also be proposed, as forwarded by Hodder, for example (1986, 1982). However, Mithen notes that this approach became largely marginal due to various shortcomings, including a 'lack of explicit methodology' and the advocacy of a relativist epistemology that rejected the idea that tangible criteria can be devised to discriminate between competing interpretations of the archaeological data (1999a: 122).

[5] See, for example, Flannery and Marcus (1996), Malafouris and Renfrew (2010), Refrew (1994), Refrew and Zubrow (1994), and Zubrow (1994).

[6] This is due to Evolutionary Psychology stressing the importance of pre-human environments for understanding the evolution of the human cognitive architecture (Tooby & Cosmides, 2005: 22). Any

The second area of research, termed 'evolutionary-cognitive archaeology' (Mithen, 1999b: 122-123; Wynn, 2009), focuses on the archaeological data from the Palaeolithic period (Nowell, 2001: 20). It is this form of cognitive archaeology that is most relevant for Evolutionary Psychology because it relates to those environments/conditions that were formative to the evolution of the human cognitive architecture. The theory and methods of evolutionary-cognitive archaeology, together with discussions of pertinent case studies, will be considered in detail below.

3.3. Evolutionary-cognitive archaeology

Evolutionary-cognitive archaeology (ECA hereafter) focuses on the evolution and development of human cognition/intelligence, language, tool use, and symbolic behaviours (Nowell, 2001: 20; Preucel, 2006: 152). An explicit assumption adopted by researchers in this area is that the archaeological record can provide insights into prehistoric cognition. Wynn, for example, states that the various approaches that comprise ECA share the conviction that: '…prehistoric minds structured prehistoric action, and that archaeology has access, albeit limited, to those minds' (2009: 145). ECA researchers are therefore faced with a unique challenge when compared to other areas of cognitive archaeology (or, indeed, archaeology generally): the challenge of interpreting material culture and archaeological residues of members of the genus *Homo* prior to the emergence of modern humans (Nowell, 2001: 21).

Though all branches of ECA are conceptually rooted in evolutionary theory, '…the only viable unitary theory in the human sciences', and researchers adhere to the general claim

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examination of stone tool production from an Evolutionary Psychological perspective will therefore focus more on the Palaeolithic data relating to cognitive evolution and stone tool production.

that the human anatomy (including the cognitive architecture of the brain) is a product of natural selection (Preucel, 2006: 152), ECA still '…remains a largely inchoate amalgam of approaches' that incorporates '…an eclectic array of interests, methods and theories' (Wynn, 2009: 145). Indeed, this may be due in no small part to ECA researchers actively adopting a multidisciplinary approach, combining archaeological theory, methods and data with those from fields such as primatology, psychology, cognitive science, neuroscience and biology (Nowell, 2001: 20; Roux & Bril, 2005). However, it should be noted that these various fields also adopt archaeological/palaeoanthropological theory, methods and data when appropriate for the aims of their research (for example, see Russon & Begun, 2004).

Within this multidisciplinary milieu, with its broadly shared aim of examining the evolution of intelligence, ECA fulfils a role that is both distinctive and significant. The most obvious contribution that archaeology has to make concerns the wealth of data from palaeolithic contexts that can be made available to researchers (Nowell, 2001: 28). In addition, the interpretation of such data is a further area in which archaeologists are uniquely placed to contribute to ongoing research and debates, particularly in terms of how material cultures, as products of behaviour, can inform researchers regarding hominid/hominin cognitive abilities (Davidson, 2010a: 214; Mithen, 1999a: 123; Nowell, 2001: 28). The archaeological/palaeoanthropological data can therefore provide a means, in certain instances, to trace the timing of cognitive developments in the genus *Homo,* while simultaneously situating them within a wider evolutionary context (Wynn, 2002: 389).

Due to their abundance, both in terms of chronological depth (McPherron, et al., 2010; Semaw, 2006) and ubiquity in the archaeological record (due in no small part to their durability) (Davidson, 2010b: 199; Odell, 2000: 1; Wynn, 1985: 36), stone tools have formed the basis of much ECA research. One of the advantages of investigating lithic remains is their durability. Stone tools, unlike other materials that enter the archaeological record, are extremely resistant to the processes of decay or destruction (Toth & Schick, 2009: 291). To the extent that stone tools can provide insights into past behaviour, they are therefore a unique and a valuable source of data. Additionally, though the production/use of tools in general is identifiable in a diverse array of animal species, stone tool *production* is a skill that remains, on current knowledge, unique to the *Homo* and, arguably, *Australopithecine* lines (Mithen, 2007: 295).

A considerable amount of interdisciplinary literature has been published on behaviours relating to stone tools that occur in the extant great apes and certain monkey species (Bril, Dietrich, Foucart, Fuwa, & Hirata, 2009; Byrne, 2005; McGrew, 1992; McGrew, 2004; Mercader, Panger, & Boesch, 2002; Schick, et al., 1999; Visalberghi, et al., 2009), while others have examined how such behaviours might have provided a basis for later developments in stone tool producing behaviours (Marchant & McGrew, 2005). Other researchers have combined data sets from primatology and archaeology/palaeoanthropology in order to compare and contrast the stone tool producing skills of the extant great apes, extinct members of the *Homo* genus, and humans (Byrne, 2004; Gowlett, 2009; Joulian, 1996; Toth & Schick, 2009; Toth, Schick, & Semaw, 2006; Wynn & McGrew, 1989). Finally, stone tools have provided a basis for various studies regarding the proposed mental/cognitive abilities of the extinct members of the genus *Homo* (Davidson & McGrew, 2005; Gowlett, 1984, 1996, 2006; Holder, 2005; Kohn &

Mithen, 1999; McPherron, 2000; Mithen, 1996; Roche, 2005; Roche, Blumenschine, & Shea, 2009; Toth, 1982; Wynn, 1979, 1981, 1985, 1993b; Wynn & Coolidge, 2010).

Despite an apparent focus on stone tool production, however, ECA research does extend to various other areas. For example, when combined with relevant data from biology and primatology, ECA can offer new insights into, and generate novel hypotheses regarding, hominid subsistence strategies in areas such as termite foraging (Backwell & d'Errico, 2001), behaviours relating to meat acquisition/scavenging (Blumenschine, 1986; Blumenschine & Pobiner, 2006; Bunn, 1983; Bunn & Kroll, 1986; Bunn, 1981; Domínguez-Rodrigo, 1999; Domínguez-Rodrigo, Pickering, & Bunn, 2010; McPherron, et al., 2010; Potts & Shipman, 1981; Shipman & Walker, 1989), and the transport and caching of raw materials around the palaeolandscape (Blumenschine, Masao, Tactikos, & Ebert, 2008; Braun, Harris, & Mania, 2009; Braun, Plummer, Ditchfield, Ferraro, & Mania, 2008; Braun, Plummer, Ferraro, Ditchfield, & Bishop, 2009). Similarly, the emergence of later behaviours that are unambiguously unique to the *Homo* line, such as fire use (James, 1989) and projectile hunting (Thieme, 1997) are also areas examined by ECA in terms of the kinds of cognitive abilities that can be inferred (Brown, et al., 2009; Haidle, 2009).

3.3.1. ECA: Theory and Methods

In terms of the various theoretical stances regarding the nature of mind that have contributed to the formation of ECA, Wynn proposes that three main ones have been particularly influential (2009: 145). The first, the linguistic model, is based on the claim that 'modern syntactical language' represents the *sine qua non* of humanness, with other cognitive abilities being viewed as unimportant in comparison (Tattersall, 2000; Tattersall, 2009; Wynn, 2009: 145). The second, the 'action-centred' model associated with Leroi-Gourhan (1964), stresses the importance of the context in which actions occur. On this view, cognition is seen as a property that emerges when individual actors engage in a given task (Wynn, 2009: 146). The third theoretical stance that has contributed to ECA (borrowed predominantly from cognitive and developmental psychology) is the 'computational/representational' model (Wynn, 2009: 146). On this view, the mind is interpreted as a computer, with different brain states being synonymous with different computational states (Wynn, 2009: 146). Wynn proposes that two main methodological approaches emerged from these theoretical frameworks and were adopted within ECA research: the 'final products' approach and the *chaîne opératoire* (2009: 147).

3.3.2. Final Products Approach

The 'final product' approach, involves applying theoretical frameworks from the field of psychology to archaeological data in order to gain insights into the cognitive abilities that facilitated those behaviours. Indeed, Wynn was himself a pioneer of this approach. For example, in two seminal papers (1979, 1981) he utilised Piagetian theory to perform 'a rigorous assessment of the intelligence of two hominid groups' (Wynn, 1985: 41). For Piaget, human intelligence develops in four main stages which are invariant in their expression (though not necessarily in their rate of emergence between individuals): these stages are sensorimotor, preoperational, concrete operations and propositional operations (Wynn, 1985: 33). Wynn examined archaeological evidence (i.e., stone tools) relating to two hominid groups to try and locate the respective cognitive skills/aptitudes on this Piagetian scale (Wynn, 1979, 1981).

For the first group he assessed Oldowan artefacts (i.e., choppers and scrapers dating to 1.9-1.7 million years), and concluded that the 'minimum necessary competence' for their manufacture was preoperational intelligence, and that no other behaviours evident from the archaeological record could support an argument for attributing more complex intelligence to Oldowan hominids as a result (Wynn, 1981, 1985: 37). For the second group, Wynn assessed later Acheulean artefacts (i.e., bifaces/handaxes dating to approximately 300,000 years) (1979) and concluded that they 'were clearly manufactured according to operational concepts' (1985: 37). In particular, the imposition of bilateral symmetry implies that knappers of 300,000 years ago were able to mentally conceive a shape and its inverse at the same time. As Wynn states: 'Since the stone cannot be folded to provide a model for trial and error flaking, the inverse must be constructed in thought…' (1985: 37). On Piaget's view, such inversions of thought are a hallmark of operational thinking, and so Wynn concluded that the archaeological evidence in this case suggests that the handaxes were manufactured in accordance with operational concepts' (1985: 37). By extension, Wynn attributed modern human operational intelligence and organisational abilities to these prehistoric handaxe makers (1985: 39).

ECA analyses of this kind, where existing frameworks and methodologies are applied to archaeological data, can prove a profitable method of generating novel theories/hypotheses regarding the cognitive evolution in the genus *Homo*. In this case, Wynn's work led him to propose that Oldowan hominids had an ape-like level of intelligence, and that operational intelligence (essentially modern intelligence) evolved somewhere between 1.5million years and 300,000 years (Wynn, 1985: 41).

Another example of the ‘final products’ approach can be seen in Mithen’s attempt to trace the stages of cognitive development in the *Homo* line from the archaeological data (Mithen, 1996). Beginning with an exposition of the various psychological models of the human mind, Mithen develops an evolutionary model that developed in three distinct ‘architectural phases’: a first phase, where minds are ‘dominated by a domain of general intelligence’ and ‘a suite of general-purpose learning and decision-making rules’; a second phase, where the general intelligence of the previous stage is ‘supplemented by multiple specialized intelligences’ which are functionally isolated and which operate within a prescribed task domain; and a third phase, where minds with ‘multiple specialized intelligences appear to be working together, with a flow of knowledge and ideas between behavioural domains.’ (Mithen, 1996: 64)

Mithen proposes that it is only with the third phase, when knowledge specific to each domain of intelligence is freely exchanged *between* domains, that examples of distinctly human behaviour can be gleaned from the archaeological record; Mithen termed the phrase ‘cognitive fluidity’ to describe this radical new cognitive architecture that allows the free-flow of knowledge (1996: 71). Indeed, it is at this stage that the modern human mind currently exists; a fact which, for Mithen, is evidenced by our abilities to combine thoughts and knowledge from disparate domains of intelligence (1996: 70).

The focus on final products as indicators of past cognitive ability is not without problems, however. For example, the problem of equifiniality, where various conceivable means exist to arrive at a given final product, is particularly problematic. Where various means of production are feasible, and where those means carry different cognitive implications, one can only reliably attribute to the maker those cognitive abilities linked to the ‘minimum competence' required for the task at hand (Wynn, 2009: 147). There is therefore a risk of underestimating cognitive abilities in such instances.

An additional related problem in this area concerns the fragmentary nature of the archaeological data, and the highly discriminatory nature of the taphanomic processes that contribute to its formation. As Nowell notes, for palaeolithic contexts certain complex behaviours that might require more sophisticated cognition will be archaeologically invisible (such as ritual dances, or tattoos) (2001: 22). In contrast, those residues of material culture that are amenable to archaeological study (such as stone tools) may have been produced with a low level of cognitive investment.

A second problem with the 'final product' approach centres on establishing 'intent' from the archaeological data. Described by Davidson as 'the finished artefact fallacy' (2002, 2010a), this line of argument raises scepticism regarding the validity of studies (such as Wynn's) which argue that Acheulean handaxes represent examples of deliberately imposed symmetry in accordance with an internal 'mental template'. Instead, Davidson and others have proposed that the symmetrical form of the Acheulean handaxe results from 'routinized knapping procedures' (Davidson, 2010a: 222; Hayden & Villeneuve, 2009) that aim to maximise flake production from a core. On this view, symmetry is present only as a bi-product of such procedures, rather than as a quality imposed on the raw material in accordance with the specific intentions of the knapper (Hayden & Villeneuve, 2009). A handaxe can therefore never be considered a 'finished artefact' in the conventional sense. Instead, the symmetrical form and state of completion of the Acheulean handaxe is comparable to the conical sharpened point of a pencil (which also displays unintentional symmetry and is essentially never 'finished') (Hayden & Villeneuve, 2009: 1167). Finally, Davidson proposes that the ubiquity and uniformity of the symmetry displayed in prehistory may be as much a product of selective sampling by modern archaeologists than a tangible phenomenon in the archaeological data (2010a: 222).

3.3.3. The Chaîne Opératoire Approach

The second method utilised within ECA research is the *chaîne opératoire*, which focuses on reconstructing the physical gestures that contributed to the creation of material culture (Wynn, 2009: 147), rather than the 'static remains' (i.e., the final products) of past behaviours (Schlanger, 1994: 149). Schlanger, for example, offers this definition of the *chaîne opératoire* approach:

> '…it fosters an explicit concern over the processes, and not merely the states, of material culture. If the becoming of material culture and the succession of material actions can be reconstructed on the basis of static archaeological remains, then the active mind of the past may well be, after all, within reach.' (1994: 143)

With its focus on past action, the *chaîne opératoire* methodology clearly owes much to the 'action-centred' theory of Leroi-Gourhan (1964), but it also draws on another research tradition that focuses on lithic experimentation, and the replication of prehistoric techniques and methods of stone tool production (Schlanger, 1994: 145).

Wynn proposes that the *chaîne opératoire* approach presents various advantages to researchers beyond approaches that focus solely on final products. For example, he argues that in focusing on sequences of action, the chaîne opératoire approach 'side-steps' many of the problems of equifiniality (2009: 148). Though true in some respects, the degree to which this perceived advantage can be attributed to the *chaîne opératoire* approach depends on the archaeological evidence at hand. For example, when considering stone tool production, the archaeological record can, on occasion, be comprehensive enough to allow lithic refits that are extensive enough to negate alternative interpretations regarding the step-by-step flake removals engendered by the knapper (for example, see Schlanger's (1996) virtually complete reconstruction of an instance of prehistoric Levallois core reduction).

In contrast, the problem of equifiniality remains in other areas, regardless of whether one follows either a final product approach or *chaîne opératoire* approach. Compare, for instance, the rival *chaîne opératoires* of Haidle (2009) and Joulian (1996) characterising the sequences of action involved in chimpanzee nut cracking verses Oldowan flake production. Due to the vagaries of evidence in such cases, the *chaîne opératoire* approach can still result in multiple, equally feasible schemata of past cognitive actions (together with multiple possible inferences regarding past cognitive abilities).

The above caveat aside, there are distinct benefits to the *chaîne opératoire* approach when compared to the final product approach. Specifically, the *chaîne opératoire* approach generates a wealth of cognitively-oriented data (Wynn, 2009: 148). As Wynn states:

> 'A *chaîne opératoire* documents a sequence of decisions actually made by a prehistoric actor, and such decisions sequences are loaded with cognitive implications. As a method, it has provided some of our most comprehensive pictures of prehistoric minds in action…' (2009: 148).

Two prominent examples of research capturing ‘prehistoric minds in action’ are Schlanger’s refitting of ‘Marjorie’s Core’ and Roche *et al*’s refitting of hominid knapping actions from Lokalalei 2C (Roche, et al., 1999; Schlanger, 1996).

Schlanger conducted an analysis of a 250,000 year old ‘comprehensively refitted’ core (referred to as ‘Marjorie’s Core’) that was reduced via the Levallois method (1996: 231). Forty one of the flakes removed from Marjorie’s core were refitted to the core striking surface, allowing researchers to ‘…follow the actual sequence of knapping activities on an archaeological core in a way that is comprehensive, and at the finest level of resolution’ (Schlanger, 1996: 239-240). Schematic representation of the removal sequence highlighted a pattern in the flake removals whereby ‘a series of non-Levallois flakes […] is followed by either one or two Levallois flakes’, after which the process is repeated (Schlanger, 1996: 241). In examining these knapping gestures, Schlanger proposes certain principles/patterns that the knapper worked to; for example, the maintenance of the lateral and distal convexities on the core (1996: 246) and the cyclical process of removing ‘a series of non-Levallois flakes […] followed by either one or two Levallois flakes’ (1996: 241). Studies of this kind contribute much to ongoing archaeological debate, whether in a narrow sense (for example, concerning the degree of pre-planning implied by the Levallois method) (Schlanger, 1996: 247), or when considering wider issues (such as cognitive comparisons with other members of the genus *Homo*) (Schlanger, 1996: 248).

Similarly, Roche *et al*’s refitting of flake finds at Lokalalei 2C (2.43 million years ± 0:05) allowed a ‘technological analysis of the core reduction sequences’ that have provided a basis for challenging previous conceptions of the cognitive capacity and motor skills of early hominids (Roche, et al., 1999: 57). Of particular note were flake removals that indicated that the hominid knappers were 'monitoring' the core platform, and removing specific flakes in order to 'repair' platforms when necessary. Pelegrin, for example, in commenting on Roche *et al's* inferences regarding the knapping behaviours of the early hominids at Lokalalei 2C, states the following:

> '…not only could the knapper ascertain that there was something wrong with the existing platform, but s/he also occasionally interrupted the regular knapping process to correct the platform by striking off an appropriate flake – but one which was not of the same order as regular flake products.' (2005: 27)

In sum, it is clear that the two *chaîne opératoire* studies mentioned above offer insights into past action/cognitive ability that would not have been possible through the study of the final products alone. However, as with the final product approach, the *chaîne opératoire* is not without drawbacks. For example, there is currently no agreed method via which to 'describe, present, and quantify' actions sequences, resulting in a plethora of 'idiosyncratic' systems that are not amenable to comparison (Wynn, 2009: 148). Indeed, many studies attempt to communicate action sequences in a variety of ways: with core diagrams with flake removals being indicated (Roche, et al., 1999; Schlanger, 1996), with tables representing the various stages (Joulian, 1996; Schlanger, 1996) and with quite complex flow diagrams (Karlin & Julien, 1995)[7]. However, though undoubtedly a hindrance to the *chaîne opératoire* approach, this problem is clearly not terminal; one merely requires a consensus regarding the appropriate method of devising and communicating operational sequences.

[7] Note, however, that Haidle (2009) has made a recent attempt to address this very issue.

A more problematic area concerns the issue of interpretation. As Wynn notes, *chaîne opératoires* do not speak for themselves (2009: 148). Schlanger's study of Marjorie's core is a pertinent reminder of this fact. Here, despite an extensive refit allowing the reconstruction the *chaîne opératoire* of an instance of the Levallois method, various issues remain open to debate and interpretation: i.e., the existence of pre-planning and the extent to which it can be attributed to the knapper, as well as the extent to which the proposed stages and the overriding principles the knapper adhere to were real, or merely a modern construct (Schlanger, 1996).

3.3.4. Neuroscience and Lithic Experimentation/Replication Studies

Alongside the two ECA methods outlined above, there are two further methodological approaches that are relevant for the present discussion. One such approach is concerned with utilising the data and methods of neuroscience to elucidate various aspects of the evolution of human cognition; the other concerns the lithic experimental/replicative studies briefly mentioned in the section above discussing the *chaîne opératoire* approach. These approaches share much with ECA in terms of theory; regardless, however, it is only recently that attempts have been made to apply neuroscientific data within ECA research, while lithic experimental/replicative studies are not widely consulted.

3.3.5. Neuroscience

Wynn proposes that '…all understandings of the nature of mind have begun to take account of developments in neuroscience', while further predicting that 'cognitive neuroscience' will prove the focal point for the amalgamation of the various branches of

ECA into a 'coherent discipline' (2009: 146). Though the current state of research does not allow the jettisoning of the behavioural models employed in ECA altogether, it is apparent that over the past decade there has been a growing interest in incorporating the methods of neuroscience into ECA research (de Beaune, 2009; Faisal, Stout, Apel, & Bradley, 2010; Rilling, 2008; Stout, 2005, 2006, 2010; Stout & Chaminade, 2007, 2009; Stout, Toth, & Schick, 2006; Stout, Toth, Schick, Stout, & Hutchins, 2000).

The beginnings of studies focusing on examining aspects of stone tool production at the neurological level can be traced back to a pioneering study published that employed Positron Emission Tomography (PET)[8] to examine 'the relationship between stone tool-making and brain function' (Stout, et al., 2000: 1215). This study by Stout *et al* was the first study of its kind to develop 'a viable method for exploring the neuronal activity associated with stone tool technology' (Stout, et al., 2000: 1218). Focusing on Mode 1 (Oldowan) technology, the test scanned and compared the activation areas of the brain of an experienced knapper in three different contexts: at rest (as a control state), when mentally envisaging a knapping task, and when performing a knapping task (Stout, et al., 2000: 1216)

Though testing focused on a single subject, and was therefore of limited scope, the results showed significant activation in brain areas '…associated with complex spatial cognition integrating different sensory inputs, such as vision, proprioception (sensing of body position and movement), and touch' (Stout, et al., 2000: 1222). Further, it was generally observed that the brain areas associated with the stone-tool making task (i.e., association

[8] PET scans employ a radioactive tracer to record increased blood flow in areas of the brain relating to a particular task (Stout, et al., 2000: 1216).

cortex and cerebellum) were the areas that have 'shown the greatest enlargement in hominid evolution' (Stout, et al., 2000: 1222).

From this study, various methods of improving the experimental process were also suggested: for example, employing multiple subjects, using different techniques/tracers (e.g., functional magnetic resonance imaging rather than PET, and tracers that decay more slowly to allow more flexible testing conditions/methods), exploring different activation areas associated with different types of stone tool production (e.g. Oldowan, Acheulean, Levallois, or blade tools) and issues relating to handedness in tool making (Stout, et al., 2000: 1222). Indeed, several of these methodological improvements, including employing a larger sample of test subjects and the use of a tracer which allowed testing outside the confines of a scanner to render the physical gestures more 'natural', were adopted in a follow-up study (Stout, 2005: 278, 2006; Stout & Chaminade, 2007).

Focusing initially on the well-documented gulf in stone tool making skill between Oldowan hominids and the comparatively less sophisticated skills of modern great apes, Stout and Chaminade proposed to examine this difference in ability by collecting functional brain activation (PET) data from novice human subjects in three different states: firstly, when striking cobbles together in the absence of flake production (control), secondly, when trying to produce 'cutting' flakes (prior to any practice), and thirdly, when trying to produce cutting flakes after a series of practice sessions (post-practice) (Stout & Chaminade, 2007: 1092).

Generally, the results suggested that Mode 1 knapping is '…supported by a mosaic of primitive and derived parietofrontal perceptual-motor systems, including recently identified human specializations for representation of the central visual field and perception of three-dimensional form from motion (Stout & Chaminade, 2007: 1091). More interestingly, Stout and Chaminade argue that the lack of activation in brain areas associated with either ‘strategic action planning’ or ‘the representation of everyday tool use skills’ indicates that ‘abstract conceptualisation and planning’ were not central to Mode 1 behaviours (2007: 1091). In summing up their results, for example, Stout and Chaminade state:

> ‘… brain activation data indicate that the initial stages of Oldowan tool making skill acquisition are primarily concerned with perceptual-motor adaptation to task constraints and especially the discovery and exploitation of object affordances, rather than with executive planning and problem solving.’ (2007: 1098)

Further pilot studies using this approach suggest that future studies will focus on examining and contrasting the neural foundations of Oldowan and Acheulean knapping (Stout, et al., 2006).

Though it clearly represents an innovative method of examining stone tool related cognition, the neurological study of brain activation areas is not without its shortcomings. Perhaps the most obvious area of criticism for researchers interested in the cognition of hominids/hominins is that these studies focus specifically on the human brain; questions can therefore be raised regarding the extent that such studies can be employed to comment on neurological structures that are not amenable to study (i.e., past hominids/hominins). However, as Stout and Chaminade point out, the study of the human brain is still significant for researchers seeking to establish the ‘…relative demands of evolutionarily significant tasks’ (2007: 1096). Here are Stout and Chaminade again:

> 'It follows that, *if* the cerebral demands associated with the habitual manufacture of simple (i.e. Oldowan or Mode I) stone tools actually did exert selective pressure on the early hominid brain, this pressure would most likely have acted directly on some or all of the structures recruited by modern humans, and only indirectly on other brain regions. (2000: 1221-1222 - original emphasis)

Another criticism that can be directed at neurological studies is that, despite the novelty of the approach, no ground-breaking discoveries have been forthcoming. Indeed, the results presented by such studies typically combine the detailing of the brain activation areas associated with a task (e.g., the 'ventral temporal cortex' or the 'inferior parietal cortex') with the attribution of vague and relatively trivial 'specializations' (such as 'conceptual/semantic knowledge of tools' or 'perceptual-motor specializations') (Rilling, 2008: 19, 26). The latter specializations, of course, will come as no surprise to archaeologists familiar with the relevant literature relating to stone tool production. However, it should be noted that it is one thing to harbour an intuitive 'folk' conception of such specializations, but quite another to devise methods of gathering quantitative data to establish their presence in the human brain.

In sum, the neuroscientific approach seems to be one that is in its infancy, with the emphasis very much on its future potential rather than the current insights garnered from its application (Rilling, 2008: 26). There is, however, optimism regarding the potential of the neuroscientific approach to '…resolved the roles of language, actions, and representation in the evolution of the human mind' and it has prompted a potentially fruitful collaboration between researchers within the fields of archaeology/palaeoanthropology ad neuroscience (Wynn, 2009: 146-147).

3.3.6. Lithic Experimentation/Replication Studies

Lithic experimentation/replication studies explore various aspects of knapping techniques and methods. Though this area of research is loosely associated with the *chaîne opératoire* approach, it affords only a tacit reference to the action-centred model. For example, research conducted from this perspective is less concerned with the characterisation of action sequences, and focuses instead on establishing which specific behaviours/abilities can be viewed as essential constituents of stone tool production 'skill' or 'expertise'. Geribas, Mosquera and Vergès, for example, note that studies in this area have two main objectives: the first is '…understanding the complexity of making stone tools', while the second involves '…characterising expertise in stone knapping' (2010: 2858). In methodological terms, the exploration of the complexity of the actions required for stone tool production is to be achieved by comparing '…the performance of people with different degrees of expertise' (Geribàs, et al., 2010: 2858).

Early work in this area by Newcomer (1971) and Schick (Schick & Toth, 1993), for example, sought to formulate criteria to identify expertise, or the lack of it, in the manufacture of handaxes. Winton, following up on Newcomer and Schick's conclusions, conducted tests to examine the various ways in which novice knappers struggle with the different stages of handaxe manufacture (2005: 110-111). In addition, a recent volume of the Journal of Archaeological Method and Theory (2008) was dedicated to exploring the ways in which researchers are approaching the subject of skill in stone tool production both methodologically and theoretically (Bamforth & Finlay, 2008: 2). Various papers in this volume utilised replication studies to explore issues such as the archaeological identification of novice flint-knappers (Ferguson, 2008), methods of discriminating between individuals via their skill level from archaeological data (Finlay, 2008), and the ways in which children's 'play' knapping activities could potentially contributed to the archaeological record (Högberg, 2008).

More recently still, studies have been conducted by various researchers to examine the 'technical gestures' associated with stone tool production, the degree to which knappers 'intend' their final products, and how knappers of various skill differ in mediating their actions to account for differing conditions. Geribas *et al*, for instance, attempted to compare the ability of expert and novice knappers to copy a simple hand axe from a visible model, with the overall aim of cataloguing which '…technical gestures have to be learned in order to successfully produce stone tools' (2010: 2865). Indeed, they claim to identify three gestures that need to be mastered for bifacial knapping: '…the type of percussion support, the position of the blank and the angle of blow' (Geribàs, et al., 2010: 2857). Further, they propose that future studies in these three areas may be profitable in developing our understanding of '…how stone knapping is acquired, how bifacial stone tools emerged and what cognitive challenges early handaxe makers had to face' (Geribàs, et al., 2010: 2857).

Others have designed experiments which seek not only to compare the products of expert, intermediate and novice knappers, but also to record how accurately those products match the intentions of the knappers prior to a flake removal (Nonaka, Bril, & Rein, 2010). For example, Nonaka *et al* conducted tests where subjects were asked to predict (by marking on the core) the size and shape of the flake they intended to detach (2010: 4). The results showed that only those knappers who were considered experts (i.e., had more than twenty years active knapping experience, verses a few years for intermediates and none for novices) were able to accurately predict the size and shape of a flake prior to the actual physical flake removal (Nonaka, et al., 2010: 8). Indeed, other distinctive behaviours that only expert knappers exhibited were also documented. For example, expert knappers tended to remove longer flakes (despite being unprompted) when compared to intermediate and novice knappers; expert knappers selected only flat or convex core surface striking platforms; and finally, only with the expert knappers did the variation of blow strength coincide with tangible outcomes, such as increased accuracy accompanying a reduced blow strength, or increased flake lengths accompanying increased blow strengths (Nonaka, et al., 2010: 8-9)

In another series of tests Bril *et al* compared how knappers with different skill levels (i.e., novice, intermediate and expert) regulate the kinetic energy of a hammerstone blow under varied conditions (Bril, Rein, Nonaka, Wenban-Smith, & Dietrich, 2010: 827). Subjects were tested under three sets of conditions. In the first, the test subjects were asked to produce reasonably sized flakes with both heavy and lightweight hammerstones, with the results supporting the hypothesis that only the expert knappers were more able to '…perceive changes of the weight of the hammer and consequently modify their striking movements accordingly' (Bril, et al., 2010: 828-829). In the second test, the subjects were asked to select and use 'self-preferred' hammerstones to remove flakes that were morphological similar to 'model' flakes presented to them (model flakes were of two sizes only: large and small) (Bril, et al., 2010: 830). Results in the case of this second test suggested that only expert and intermediate test subjects were able to remove larger flakes when they increased the force of the hammerstone blow (novice subjects were aware of the 'in principle' need to increase blow strength in such cases, but failed to remove larger flakes) (Bril, et al., 2010: 833). Finally, the subjects were asked to remove large/small flakes to match a 'model' flake while using both light and heavy hammer stones (Bril, et al., 2010: 833); again, the results suggested that, despite the fact that all the groups regulated their behaviour according to accommodate differing task conditions (i.e., different combinations of goal flake size and hammerstone size), '…only the experts were able to fine-tune their actions in such a way to ensure goal achievement indicative of dexterity (Bril, et al., 2010: 836).

As with the neuroscientific studies discussed above, a perceived drawback of this approach is that the results are rather predictable. Particularly evident from the most recent examples (Bril, et al., 2010; Geribàs, et al., 2010; Nonaka, et al., 2010), critics could argue that researchers tend to focus on testing 'skill' and 'expertise'[9] in areas that are already known to be important for stone tool production from 'folk' interpretations. Admittedly, the methods of testing are novel, and it is obviously worthwhile from a scientific perspective to gather quantifiable data where feasible. However, as with the neuroscientific data, the results will raise no eyebrows among archaeologists who have any knowledge of stone tool production.

3.4. Evolutionary Psychology, ECA and Stone Tool Production

As Wynn notes, the form of Evolutionary Psychology espoused by Tooby and Cosmides has gained little traction in ECA circles, despite the fact that it could be viewed as a fourth theoretical approach to ECA (2009: 146). This is arguably to the detriment of both fields, since the adoption of methodology of Evolutionary Psychology has the potential to

[9] Note that one could also question whether 'skill' and 'expertise' represent terms that are concrete enough on which to base a scientific study. Bamforth and Finaly, for example, acknowledged that 'skill' is a term that suffers from a lack of satisfactory definition (though they claim that such 'conceptual ambiguities' can be exploited to broaden research in this area) (2008: 22).

generate new forms of data, to produce potentially novel results, and provide challenges to the prevailing assumptions regarding how stone tool producing behaviours are acquired.

One such assumption, widespread among researchers, is that stone tool producing behaviours are acquired through social learning alone, and are therefore wholly explicable in such terms (Davidson & McGrew, 2005: 809; Ferguson, 2008; Roche, et al., 2009; Shea, 2006: 213). Though social learning clearly fulfils a pivotal role in acquiring the skills of stone tool production in the sense that individuals do not spontaneously adopt such behaviours without some form of social stimulus/scaffolding, this does not negate the possibility that an innate capacity might exist in the human cognitive architecture which facilitates the acquisition of such skills.

Indeed, for Evolutionary Psychologists, the evocation of 'learning' as an explanation for any behaviour simply begs a further questions regarding the cognitive basis of the learning itself. Cosmides and Tooby, for example, state the following:

> 'The common belief that "learning" is an alternative hypothesis to an evolutionary theory of adaptive function is a category error. Learning is a cognitive process. An adaptive function is not a cognitive process; it is a problem that is solved by a cognitive process. Learning is accomplished through psychological mechanisms (whose nature is not yet understood), and these were created through the evolutionary process, which includes natural selection. Consequently, the issue is not whether a behaviour is the result of natural selection "or" learning. The issue is, What kind of learning mechanisms would natural selection have produced?' (1987: 292)

Interestingly, Cosmides and Tooby argue that learning mechanisms will be 'specialized for quick and efficient learning about an evolutionarily important domain of human activity'

(1987: 291). This definition presents an obvious problem to any proposition that the learning of stone tool production is governed by dedicated psychological mechanisms, because one would struggle to describe modern human skills and abilities in this area as either quick or efficient. However, from the perspective of Evolutionary Psychology this fact does not provide adequate grounds to reject the notion that psychological structures may exist to mediate stone tool producing behaviours.

Two main contributing factors may be suggested to explain this apparent inconsistency; factors which still allow for the existence of such psychological mechanisms, but which bring into question various assumptions on which current methods of testing are based. The first concerns the framework for comparison regarding the 'inefficiency' of modern humans in learning stone tool producing behaviours; the second considers how the 'background conditions' of testing may hinder the expression of cognitive structures in the human brain.

When faced with the fact that the learning of stone tool production is neither quick nor efficient (as one would expect if psychological mechanisms dedicated to skill acquisition exist in the human cognitive architecture), one must initially questioning the basis of the comparison. With what kinds of learning, for instance, are tacit comparisons being made when it is asserted that modern humans do not acquire the skills of stone tool quickly or efficiently? The answer is learning from other task domains, which consist of quite different, potentially disparate, problem types. The mechanisms that govern the ways humans learn to walk, for example, are very efficient, but the problems solved in the learning process share little common ground with those of stone tool production.

Tooby and Cosmides refer phenomena such as learning to walk as ‘natural competencies’; i.e., task domains where the associated problem types are solved so efficiently by the underlying architecture of the human brain that the process appears effortless or ‘natural’ (Tooby & Cosmides, 1992: 95, 2006: 188). Therefore, to the extent that stone tool production comprises a distinct task domain, consisting of unique problem types, any cross-domain comparison regarding efficiency is effectively negated. Meaningful comparison can only be made where proof of parity is forthcoming in all, or at least some, of the problem-types under consideration.

Putting aside the issue of the implicit and inappropriate comparisons of dissimilar task domains, however, one could argue that the process of learning stone tool production is still demonstrably slow and inefficient in modern humans. Further, one might ask how this can be the case if the learning process is governed by evolved psychological mechanisms. A possible explanation for this may be found via a consideration of the ‘background conditions’ under which stone tool production skills were (and, more importantly, *are*) learned.

For Tooby and Cosmides, any psychological mechanism that governs learning in a specific domain is attuned to operate according to ‘information and conditions that were reliably present in ancestral environments’; this relationship maintains for any such mechanism both in ‘the developmental process’ and ‘in its mature state’ (2005: 22)’. The efficiency of the psychological mechanism – its ability to operate as a ‘successful problem solver’ – may therefore be disrupted if current learning conditions deviate from those that reliably recurred in the EEA (Tooby & Cosmides, 2005: 22)[10].

Now, one could argue that there exists a glaring contrast between ancestral and modern environments in terms of the prevalence of stone tool producing behaviours. In contrast to contexts ancestral to modern humans, where stone tool production has been largely ubiquitous for the past 2.5 million years (Stout & Chaminade, 2009: 85), stone tool production does not constitute an important part of the human developmental milieu in the majority of modern contexts. Shea, for example, notes that for most westerners direct experience of stone tool production is not encountered until college archaeology classes (2006: 214), which is itself a context far removed from the widespread practical and adaptive role that stone tool production formerly fulfilled (Stout & Chaminade, 2009). Further, what we know about the specific details of the stone tool production behaviours, in terms of the former processes of acquisition and adaptive utility, is restricted to what can be gleaned from the archaeological record or a small number of ethnographic examples (see, for example, Stout, 2002)[11].

However, though stone tool production behaviours are now largely absent in modern contexts, from the perspective of Evolutionary Psychology one may posit that the human brain will retain any cognitive structures relating to stone tool production. This is because, as Tooby and Cosmides argue, radical changes in the human cognitive architecture (as with

[10] Note, however, that there is another possibility – that any psychological mechanism/mechanisms mediating those behaviours are operating as they did in the past, but the information processing problems of stone tool production are largely intractable. Despite any apparent inefficiency in the learning process, therefore, the 'solution' embodied by the psychological mechanism may be the most efficient (or, indeed, the only) cognitive solution possible.

[11] Indeed, the rare ethnographic cases that do exist need to be treated very cautiously. For example, ethnographic examples may represent an atypical form of stone tool producing behaviour. Further, the conditions under which their stone tool producing skills are acquired are wholly modern, and so may not provide an accurate model for those conditions prevalent in the EEA.

any other complex physical change) take time: '… major and intricate changes in innately specified information-processing procedures present in human psychological mechanisms do not seem likely to have taken place over brief spans of historical time' (1989: 34).

Potentially, therefore, and despite the lack of relevant stimuli in modern contexts, the human cognitive architecture may retain the capacity to efficiently solve the various information-processing problems of stone tool production. Such cognitive structures are described as 'dormant' in instances where their expression will only become apparent once EEA-type conditions are encountered[12]:

> '… the adaptive specializations that are expected to constitute the majority of our neural architecture are designed to remain dormant until triggered by cues of the adaptively significant situations that they were designed to handle.' (2006: 189)

In one sense, the conjectured 'dormant' nature of any prospective psychological structures dedicated to solving the information-processing problems of stone tool production can be seen as advantageous, because the application of the methodology of Evolutionary Psychology in this area has the potential to identify genuinely novel cognitive capacities. Indeed, current methods of testing within ECA, though of clear value within the theoretical/methodological boundaries of each approach, are inadequate for such a purpose[13]. A focus on examining either skill/expertise or knapping action sequences has

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[12] In lamenting the paucity of ethnographic literature on stone knapping, Davidson and McGrew briefly note that some such studies present 'substantial anecdotal evidence that children begin hitting rocks together when in the company of other knappers' (2005: 807). Arguably, such behaviours might not develop in the majority of children in modern western contexts due to the absence of sustained or relevant stimuli.

[13] The neurological studies mentioned above perhaps come closest to proving the existence of cognitive 'specializations' relating to stone tool production (Rilling, 2008; Stout, 2010; Stout & Chaminade, 2007). Note, however, that from these studies such 'specializations' can only be said to be 'associated with' stone tool production. Further testing may indicate that the same areas are implicated in other types of manual task, and so cannot be considered specific to stone tool production alone.

obvious limitations if the cognitive architecture that is generating the data consists of psychological mechanisms that are operating sub-optimally due to complications relating to the background conditions of the task domain.

Conceivably, therefore, the current state of testing in the area of stone tool production may be akin to another example forwarded by Tooby and Cosmides: that of human colour vision. Imagine one is asked to conduct tests to collect data on the properties of human colour vision, but with one important caveat: tests can only be conducted under street lights (Tooby & Cosmides, 1992: 73). In the process of testing, one would find that certain aspects of the physical system that allow humans to see in colour will still operate (i.e., the retina will still collect light, and the brain will still process the information provided to it in a way that test subjects interpret as 'seeing'), however, at the same time the true extent of the capabilities of the system remain untried and untested. This circumstance is due to the background conditions of the test itself not accurately reflecting those of the EEA; i.e., only a rough approximation of natural light, the background conditions to which the human visual system is most closely adapted, is employed in the test. Referring to this example, Tooby and Cosmides state the following:

> '…a mechanism that was capable of producing an adaptive target under ancestral conditions may not be capable of doing so under modem ones. Our visual system fails to maintain colour constancy under sodium vapour lamps in modem parking lots […] and attempting to understand colour constancy mechanisms under such unnatural illumination would have been a major impediment to progress.' (1992: 73)

From the perspective of Evolutionary Psychology, a similar 'impediment to progress' could arguably be obstructing current testing methods in the area of stone tool production.

Various skills and abilities associated with the task domain may have gone unexplored due to the fact that the background conditions of testing do not accurately reflect those of the EEA.

Despite these criticisms of the current approaches to testing within ECA, however, it is clear that the data collected in the area of stone tool production, as well as in the field of Palaeoanthropology in general, must play a central role to any application of the methodology of Evolutionary Psychology in this area. For example, Evolutionary Psychology stresses the importance of examining how a given adaptive problem manifested itself in Pleistocene conditions (Laland & Brown, 2002: 164; Tooby & Cosmides, 2005: 16). The archaeological data will be crucial in this respect for tracing stone tool production/use through time, assessing how the associated adaptive problems may have changed and evolved, and identifying any reliably recurrent problem types that feature for any instance of stone tool production.

Similarly, the methodology of Evolutionary Psychology also requires a ‘task analysis’ to be performed for the adaptive function under consideration, which entails identifying the properties a psychological mechanism would need to exhibit to solve the problems associated with stone tool production (Tooby & Cosmides, 2005: 16). To this end, the various works described above documenting, and testing for, various aspects of skill and expertise (Bril, et al., 2010; Geribàs, et al., 2010; Nonaka, et al., 2010), as well as works reconstructing *chaîne opératoire* (Schlanger, 1996) represent invaluable sources of data. Indeed, a further potentially profitable data source that could be consulted and incorporated into a task analysis concerns experimental work examining the fracture mechanics of stone (Dibble & Pelcin, 1995; Dibble & Rezek, 2009; Pelcin, 1997b; Speth, 1972, 1974, 1975, 1981). After all, the raw material utilised in the process of making stone tools represents an 'enduring structure of ancestral environments' (Tooby & Cosmides, 1992: 72); one could therefore explore the prospect of a putative psychological mechanism being attuned specifically to the kinds of problems indicated by such studies.

3.5. Conclusions

To conclude, in this chapter I first provided an overview of the field cognitive archaeology, with a particular focus on ECA, the branch of cognitive archaeology most relevant for applying the methodology of Evolutionary Psychology to the area of stone tool production.

I then discussed the advantages and limitations of the two main methods utilised within ECA (namely, the 'final product' method and the *chaîne opératoire)*. Two studies where the 'final products' approach has provided useful insights into past cognitive abilities were discussed, while several drawbacks of the approach were also highlighted. First, it was argued that equifiniality necessitates minimum competence attribution in terms of cognitive complexity where a task can be completed in various ways, and that one risks underestimating past cognitive capacities as a result. Second, the problem of establishing the finality of the products of stone tool production was considered, particularly with reference to the 'finished article fallacy' and the notion that morphological features associated with intent (typically symmetry) may simply be a by-product of knapping procedures aimed at maximising flake production.

Similarly, two studies adopting the *chaîne opératoire* approach were discussed that I argued offer insights into past action/cognitive ability beyond those attainable through the final product approach. Various limitations of *chaîne opératoire* were also highlighted, including the idiosyncratic recording methods that complicate meaningful comparisons, the possibility of multiple viable *chaîne opératoire* for a given knapping episode (equifiniality), and the fact that reconstructions of the kind presented in the two case are very much contingent of the vagaries of the archaeological material.

Two further related approaches with data sets relevant to the field of ECA were also considered (i.e., neuroscience and lithic experimentation and replication). Though the ingenuity of the neuroscientific approach was acknowledged, I argued that this approach is still in its infancy and has produced no ground-breaking discoveries to date. Regarding lithic experimentation/replication, I discussed various studies that have the prospect of contributing valuable data and methodologies to the study of stone tool producing behaviours from the perspective of Evolutionary Psychology.

Finally, Chapter 3 includes a consideration of the prospective contributions that Evolutionary Psychology can make to the study of stone tool production. I argued that adopting the perspective of Evolutionary Psychology has the potential to challenge some of the existing assumptions on which current studies into stone tool production are predicated. Specifically, I argued that adopting an Evolutionary Psychology approach entails challenging the assumptions that social learning alone can account for skill acquisition and that skill acquisition is inefficient. Instead, Evolutionary Psychologists would argue that skill acquisition will be guided by evolved psychological mechanisms, and that the perceived inefficiency of our cognitive capacities in the area of stone tool production may be due to the fact that modern contexts lack developmental stimuli that are consistent with EEA conditions.

As well as challenging pre-existing assumptions, I also argued that Evolutionary Psychology offers the prospect of developing alternative methods of testing and data collection, which in turn have the potential to identify novel cognitive capacities associated with stone tool production. To this end, the research collected from an ECA perspective to date will prove invaluable. Far from maintaining a ‘cultivated ignorance of the palaeoanthropological record’ (Wynn, 2009: 146), or aspiring to conduct research that is ‘footloose and fossil-free’, (Stone, 2002: 420), an Evolutionary Psychological study of stone tool production will necessarily require an extensive consultation of the ECA literature, as well as the incorporation of the broad range of its data.

Chapter 4: The Hard and Soft Hammer Percussion Techniques As Adaptive Problems

4.1. Introduction

This chapter begins by arguing that employing the methodology of Evolutionary Psychology to examine stone tool producing behaviours requires, in the first instance, that the associated problem types be demarcated. To this end, I argue that stone tool producing behaviours can be broadly demarcated into the techniques and methods of production, and that one can further demarcate the various identifiable techniques and methods in order to establish distinct problem types. As a result of this demarcation of problem types, I propose to apply the methodology of Evolutionary Psychology to examine each of the following: hard hammer and soft hammer percussion (for techniques) and the biface and Levallois (for methods). The rationale for focusing on these specific areas is provided below.

Chapter 4 proceeds to examine the extent to which archaeological evidence can be used to demonstrate that hard and soft hammer percussion fulfil the criteria employed by evolutionary psychologists to identify an adaptive problem (the first step of the methodology of Evolutionary Psychology). For evolutionary psychologists, adaptive problems have two defining characteristics: they must be reliably recurrent and have consequences relating to fitness (i.e., survival or reproduction). Regarding recurrence, Tooby and Cosmides, propose that adaptive problems are:

> '…conditions or cause-and-effect relationships that many or most individual ancestors encountered, reappearing again and again during the evolutionary history of the species, giving natural selection enough time to design adaptations in response.' (2005: 21-22).

The recurrence of an adaptive problem is of paramount importance because complex cognitive adaptations are unlikely to evolve in response to sporadic selection pressures; as a result, only '…those conditions that recur and accumulate statistically across generations lead to the construction of complex adaptations' (Tooby & Cosmides, 1992: 69). Establishing the recurrence of an adaptive problem requires, in the first instance, ascertaining chronological depth. An adaptive problem that does not predate 10,000 years, for example, would be unlikely to have a corresponding psychological mechanism attuned to solving the specific information-processing problems involved, even if those problems reliably recur over generations. As Tooby and Cosmides state:

> '…natural selection operates far too slowly to have built complex information-processing adaptations to the post-hunter-gatherer world of the last few thousand years.' (2006: 181)

Recurrence also requires demonstrating that the task domain remains consistent over time in terms of the problems it presents. Variation in the types of problem encountered in the task domain of hard or soft hammer percussion may stem from environmental factors (e.g., variable fracture properties in the raw material) or behavioural factors (i.e., the problem of equifiniality may be an issue if various different behavioural strategies can result in same technological outcome).

Regarding fitness consequences, one needs to demonstrate, as far as is feasible given the fragmentary nature of the archaeological evidence, that the successful solution of an adaptive problem proffers an advantage (however small) in terms of survival or reproduction. Psychological mechanisms are formed over time by natural selection through the retention or discarding of alternative designs on the basis of how well they solve an adaptive problem, and, concomitantly, promote fitness (Tooby & Cosmides, 2005: 21-22).

Establishing that the percussion techniques under consideration are viable adaptive targets for the evolution of dedicated psychological mechanisms, therefore, requires assessing whether they fulfil these criteria: i.e., they are problems that recur reliably over time, and there are fitness consequences associated with the successful solution of those problems instantiated in their application. Below, I will consider these techniques in turn, first providing a definition, and then outlining the ways in which each can be identified archaeologically. I will then consider, with reference to the relevant archaeological data, the extent to which the hard and soft hammer percussion techniques can be viewed as adaptive problems according to these criteria.

4.2. Technique and Method

When looking to identify possible adaptive targets associated with stone tool producing behaviours, one first needs to recognise that an umbrella term such as 'stone tool production' is of little conceptual use due to that fact that stone tool production comprises a heterogeneous suite of problem types, with multiple potential adaptive targets. Any putative psychological mechanism may therefore be dedicated to solving some, even many, of the various sub-tasks implicated in stone tool production behaviours (to the extent, at least, that viable adaptive targets can be identified in these sub-tasks), and it is these sub-tasks that therefore need to be focused upon.

One therefore requires a means of delineating the various adaptive problems/targets associated with stone tool production into distinct sets. One potentially useful demarcation is provided by Pelegrin (1990; 2005), who draws on the earlier work of Tixier (1967)[14]. Pelegrin stresses the distinction between the 'technique' and the 'method' of stone tool production, and defines the two terms as follows:

> 'The word technique refers to the physical modes of executing flake detachments. They are associated with several parameters: the nature of the application of force (direct percussion, indirect percussion, pressure); the nature and morphology of the knapping tool (hard stone, soft stone, wood billet, etc.); and the manner in which the knapped object is held and the body position of the knapper (on an anvil, other support, freehand, etc.). The word method refers to the spatial and chronological organisation of the removals from a knapped object. When the organisation is repeated in an archaeological assemblage – which is often the case – a knapping method is identifiable.' (Pelegrin, 2009: 96)

By adopting this distinction, we are therefore presented with two different avenues of enquiry regarding the information-processing problems associated with stone tool production; those of technique, and those of method. This distinction is an important one because different information-processing problems may be associated with different areas of both technique and method, and each arguably has a distinct evolutionary history. Over

[14] More recently, Moore has proposed a similar distinction between two aspects of stone tool design. The first, termed 'engineering' design, is concerned with the 'techniques that cope with the latitude offered by the mechanics of stone fracture defining the boundaries of design space' (i.e., appreciation of the connotations of blow application, the potential and limits of what is possible via flake removal), and 'formal' design, which 'assembles engineering techniques to produce a tool' (Moore, 2010: 17).

the course of prehistory, therefore, psychological mechanisms may have evolved in the human cognitive architecture to solve the information-processing problems for some techniques or methods, but not for others, or for specific areas of some techniques/methods, but not others.

For the purposes of this thesis, I propose to examine two stone tool production techniques and two stone tool production methods via the methodology of Evolutionary Psychology: for the techniques I will examine the hard hammer percussion technique and the soft hammer percussion technique, and for the methods I will examine the biface method (typically associated with the Acheulean handaxe) and the Levallois method.

The rationale for focusing only on those techniques and methods outlined above is three-fold. The first is that the archaeological record demonstrates that the techniques and methods cited are chronologically deep-seated. One could therefore argue that the prospects of selection pressures leading to the evolution of a distinct psychological mechanism to facilitate their use are more favourable. The second reason for focusing on the techniques and methods outlined above concerns the wealth of data that is available to incorporate into this study. The archaeological evidence can provide important insights regarding the timing and context for the emergence of these techniques and methods I am proposing to examine (Wynn, 2002), while crucial data relating to the techniques and methods under consideration can also be garnered from reconstructions of knapping behaviours (Boëda, 1995; Chazan, 1997; Newcomer, 1971; Otte, 1995; Schlanger, 1994, 1996; Van Peer, 1995; Whittaker, 1994), studies of modern day acquisition of knapping skills (Bril, Rein, Nonaka, Wenban-Smith, & Dietrich, 2010; Geribàs, Mosquera, & Vergès, 2010; Nonaka, Bril, & Rein, 2010; Winton, 2005), the biomechanics of knapping gestures (Dapena, Anderst, & Toth, 2006; Williams, Gordon, & Richmond, 2010) and examinations of raw material properties (Cotterell, et al., 1985; Dibble & Pelcin, 1995; Dibble & Rezek, 2009; Pelcin, 1997b; Speth, 1972, 1974, 1975, 1981). Thirdly, the necessary limitations of the present study in terms of the scope of the thesis are also a factor. Focusing only on the techniques and methods above will afford a rigorous application of the methodology of Evolutionary Psychology in this area while allowing a thorough consideration of the relevant archaeological data (something researchers in Evolutionary Psychology have often been criticised for failing to do in the past) (Wynn, 2009: 146).

4.3. Defining the Hard hammer percussion technique

The hard hammer percussion technique involves freehand, direct percussion with the dominant and non-dominant hands performing distinctive roles in the production of a co-ordinated action (see Figure 4.1). A stone hammer held in the dominant hand (called the hammerstone) is used to strike a stone cobble/block (referred to as the core) held in, or supported by, the non-dominant hand; the percussive blows applied with dominant hand detach flakes (Toth & Schick, 2009: 291; Wynn, 2002: 391).

Figure 4.1: An illustration of hard hammer percussion. A core held in the non-dominant hand is struck with a hammerstone held in the dominant hand in order to remove flakes (adapted from Mithen, 1996: 97).

Though the hard hammer percussion technique represents an ostensibly simple form of knapping, it should be noted that it involves the application of blows which are carefully directed, rather than arbitrarily applied (Wynn, 2002: 391) in order to exploit specific aspects of the fracture properties of the raw material employed. As Whittaker notes, stone tool production of any kind involves the appreciation, and control, of the principles of 'conchoidal fracture' (1994: 12). Conchoidal fracture refers to the way in which the force from a blow the disperses through a material from the point of impact and spreads uniformly in a 'Hertzian cone' (See Figure 4.2) (Pelegrin, 2005: 24-25; Whittaker, 1994: 12).

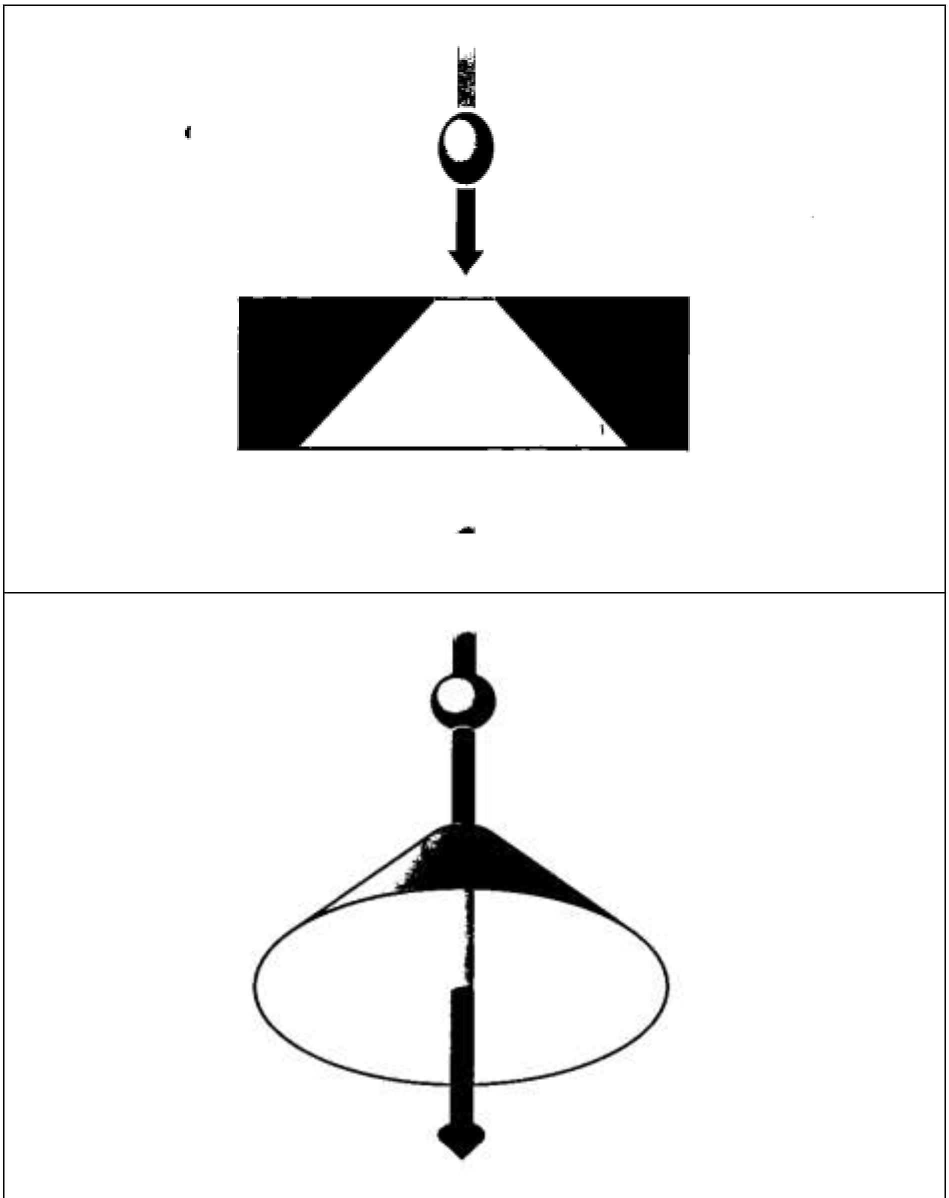

Figure 4.2: The 'Hertzian cone' phenomenon. Two dimensional (top), and three dimensional (bottom) diagrams showing the 'Hertzian cone' phenomenon. From the point of impact, the force disperses through the material in a uniform cone shape (after Pelegrin, 2005: 24).

It is the reliably recurring outcome of conchoidal fracture that allows the knapper to use the hard hammer percussion technique in ways that are predictable and, to an extent, controllable:

> ‘By changing the forces, the angles, and the shapes of the surfaces involved, the shape and direction of the conical fracture can be controlled, and a piece of rock fractured in desirable ways.’ (Whittaker, 1994: 12)

Any reference to the hard hammer percussion technique will therefore refer to the use of hard hammer percussion involving directed, co-ordinated blows which exploit the embedded conchoidal fracture properties of the raw material.

4.3.1. Archaeological Identification

Hard hammer percussion can be identified archeologically through diagnostic traces that the technique leaves behind on the raw material. Specifically, where features associated with conchoidal fracture are identifiable on lithic artefacts, archaeologists surmise that hard hammer percussion was employed. Archaeologists cite two diagnostic features on lithic remains that indicate conchoidal fracture has occurred. The first is referred to as the ‘bulb of percussion’ (Pelegrin, 2005: 23) (see Figure 4.3). The force of the hammerstone blow produces a diagnostic ‘lump’ directly below the point of impact which is visible, and palpable, on the removed flake, while the core displays a ‘negative bulb’. The second diagnostic feature of conchoidal fracture consists of diagnostic ‘ripples’, visible on both the core and the flake, that are the product of the force of the blow dispersing through the material.

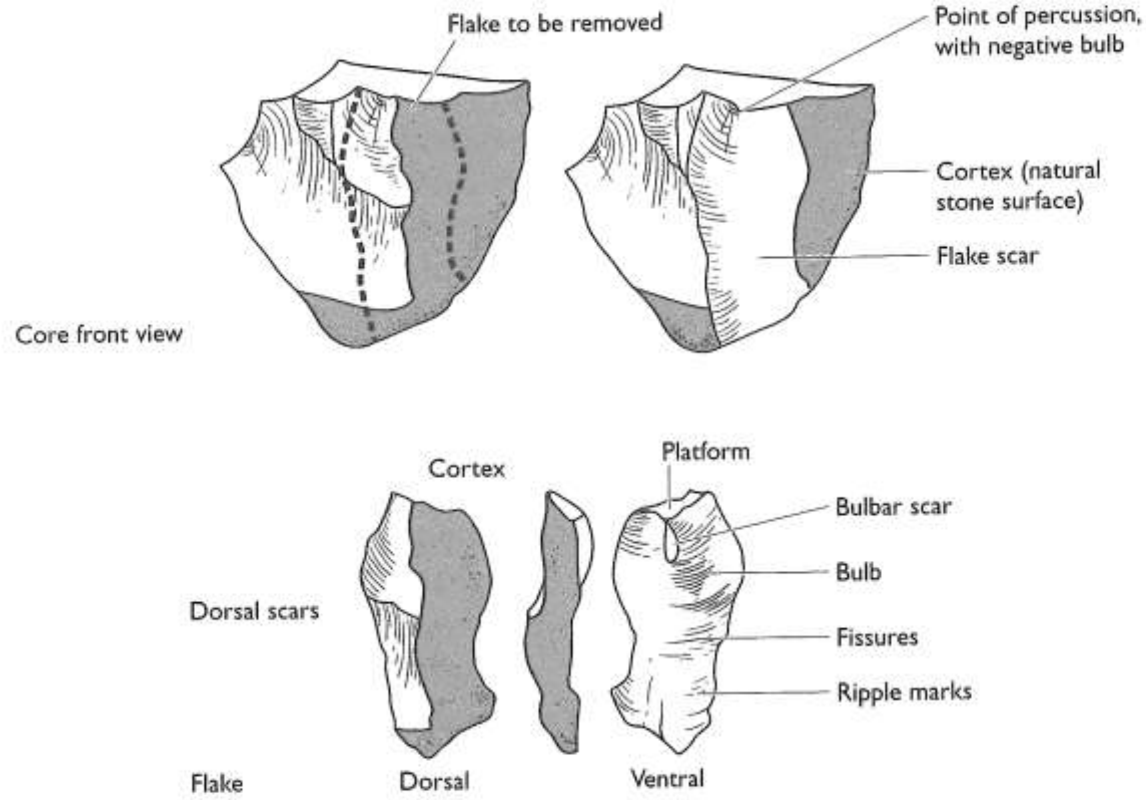

Figure 4.3: Diagram showing the diagnostic features of the hard hammer percussion technique. Top left: core prior to flake removal (with dashed lines to indicate the flake that will be detached. Top right: core after the flake is removed, displaying negative bulb of percussion. Bottom: Dorsal, profile and ventral views of the flake removed from the core. The ventral view in particular displays the diagnostic features of conchoidal fracture (i.e. the bulb/bulbar scar, also called the bulb of percussion, and ripple marks on the ventral face) (after Lewin & Foley, 2004: 317).

Though such diagnostic features are of obvious use, a degree of caution is required when positing the use of hard hammer percussion based on such evidence. For example, flakes produced by hard hammer percussion (and their corresponding cores) may be confused with the incidental by-products of various natural forces that split and break stone (e.g. the influence of fast flowing water, rocks falling from height, or the cyclical exposure to extremes of cold and/or heat). Similarly, other subsistence activities can produce conchoidal flakes as a by-product in the absence of hard hammer percussion (e.g. nut-cracking with a hammerstone and anvil, throwing stones at hard surfaces, or using the bi-polar split breaking technique[15]).

Archaeologists employ a number of strategies to distinguish between genuine cases of hard hammer percussion and cases where conchoidal fracture is only incidentally present. One such strategy involves assessing the frequency of the occurrence of conchoidal fracture within a given context in order to establish agency (Pelegrin, 2005: 25; Roche, 2005: 35); a high frequency of flakes exhibiting conchoidal fracture is strongly associated with purposive action, while low frequencies are associated with chance occurrences. Andrefsky notes that débitage signatures can also provide insights into which reduction strategies are being employed by prehistoric knappers (Andrefsky, 2009: 81). Débitage signatures are created based upon experimental replication of knapping episodes: 'control group signatures' are formed from the débitage of a given knapping technique or method, and these signatures can then be compared to excavated material to infer the which knapping activities were used (Andrefsky, 2009: 81). As Andrefsky notes, débitage signatures readily allow distinctions to be made between episodes of hard hammer percussion and bipolar splitting in lithic assemblages (2009: 82).

Lastly, other forms of evidence from a given context may support the case for the deliberate production of conchoidal flakes via the hard hammer percussion technique over rival explanations. Hammerstones, for example, that display circumscribed pitting/damage

[15] Note that bi-polar split breaking does not reliably produce flakes with the diagnostic features of conchoidal fracture, even if they are an occasional by-product of this technique. As mentioned previously, there are strict limits regarding the angle of a blow which determines whether an instance of conchoidal fracture will be evident in the debris. Typically, where a blow is struck directly from above, as is the case with bi-polar split breaking, conchoidal fracture will not be evident in the majority of the resultant flakes. Contrary to Mercader *et al* (Mercader, et al., 2002), Schick and Toth (Schick & Toth, 2006; cited in Toth & Schick, 2009: 197) argue that one can compare and distinguish the residues of deliberate percussive flaking from the by-products of nut-cracking activities.

can indicate repeated striking, from which one can posit agency. Spherical cobbles with pitting impact damage (typically classified as hard hammerstones) are a common indicator of hard hammer percussion activities in many Oldowan assemblages (Toth & Schick, 2007: 1950). Though hammerstone pitting cannot discriminate between the bi-polar and hard hammer techniques, the associated lithic assemblage may suggest which technique was employed. A high frequency of tools displaying conchoidal fracture in association with faunal remains bearing stone tool cut marks may also suggest purposive production and utilisation, rather than the action of serendipitous natural forces or the influence of subsistence behaviours unrelated to cutting (Toth & Schick, 2007: 1949). Similarly, the deliberate production of tools (and the specific use of hard hammer percussion) can be supported with evidence of the refitting of a core where the conditions of preservation in a given context are favourable (Delagnes & Roche, 2005; Roche, 2005: 39; Schlanger, 1996).

4.4. Recurrence of the Hard Hammer Percussion Technique

In order to examine whether the hard hammer percussion technique fulfils the criterion of recurrence one needs to examine the technique from two perspectives. The first concerns the examination of hard hammer percussion in terms of its archaeological occurrence, including evidence of the antiquity of the technique and the extent to which the technique recurs over prehistory. The second concerns a consideration of factors that might introduce variability into the task domain over time, thereby negating recurrence.

4.4.1 Archaeological Occurrence

To address the first of these issues, robust archaeological evidence exists for the hard hammer percussion technique being both chronologically deep seated and prevalent in the earliest contexts associated with stone tool producing behaviours. At present, the earliest evidence for the use of the hard hammer percussion technique can be seen in Oldowan tool types (also referred to as 'mode 1') that typify the lithic assemblages of various African sites located in the northern rift valley dated to between 2.6-2.2 million years (de la Torre, 2004b: 454; Pelegrin, 2005: 25; Toth, et al., 2006). The oldest examples of Oldowan tools, recovered at Gona, Ethiopia, date to as early as 2.6-2.5 million years ago (Semaw, 2000, 2006; Semaw, et al., 1997; Semaw, et al., 2003)[16]. Excavations in the early-to-mid nineties at two Gona sites (EG10 and EG12) yielded over '3,000 surface and in situ artifacts' (Semaw, 2006: 50) securely dated via $_{40}$Ar/$_{39}$Ar dating and paleomagnetic data (Semaw, 2006: 53; Semaw, et al., 1997: 333-335). Broadly similar to other Oldowan assemblages up to 1.5my, the EG10/EG12 lithic assemblage is made up of 'a large number of unifacially-flaked cores, and débitage including whole flakes, and a high density of flaking debris (split and snapped flakes, and angular fragments)' (Semaw, 2006: 56). Examples of pitted hammerstones are lacking at Gona, so evidence of the use of hard hammer percussion comes primarily from the débitage and cores/choppers (Semaw, 2006: 56). The use of hard hammer percussion can be surmised based on examples of 'well struck flakes

[16] Note that the 2.6my date represents the earliest examples of unambiguous stone tools. As Panger *et al* point out, the complexity of some of the stone tools dating to 2.6 million years ago implies that there were precursors to such behaviours which are archaeologically invisible and, as a result, the first occurrence of stone tool production may have been underestimate by 'millions of years' (2002: 243). Indeed, as Toth *et al* note, the fact that the hard hammer percussion technique is visible at a time depth of 2.6my implies that the '…cognitive and biomechanical capabilities to efficiently flake stone' had already evolved in certain hominid groups (Toth, et al., 2006: 115). In addition, other forms of evidence, such as cut marks on faunal remains from Dikika, Ethiopia, have provided a basis for inferring that stone tools may have been employed to meet subsistence needs as early as 3.39million years ago (McPherron, et al., 2010). This circumstancial evidence has been bolstered by recent finds at Lomekwi 3, West Turkana, Kenya, recovered artefacts suggests that hominids were engaging in both battering activities and core reduction, including evidence of a developing appreciation of fracture properties, as early as 3.3 million years ago (Harmand, et al., 2015).

with conspicuous bulbs of percussion’ (Semaw, et al., 1997: 335) that occur in high frequencies in the assemblage (i.e. 110 specimens or 25% of the excavated EG10 assemblage, and 58 specimens or approximately 34% of the excavated EG12 assemblage) (Semaw, 2006: 59) (see Figure 4.4).

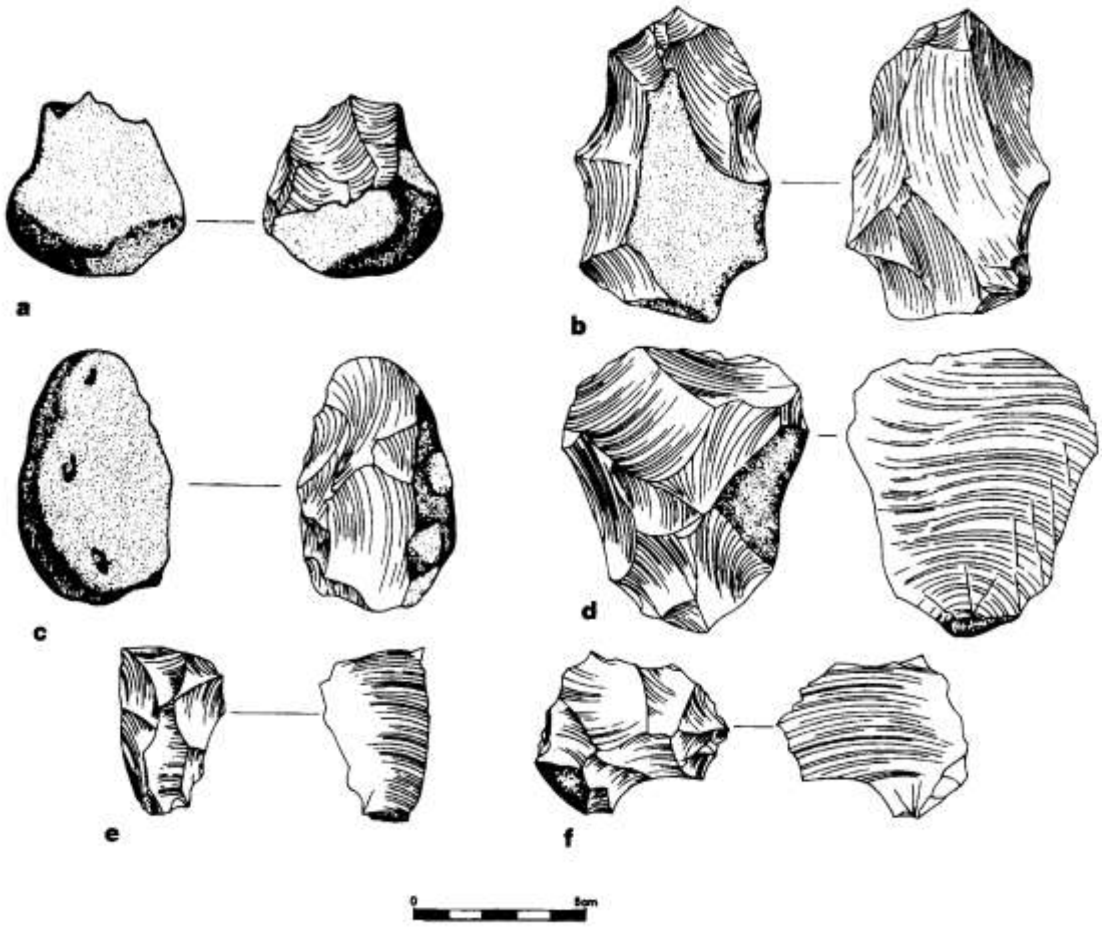

Figure 4.4: Drawings of artefacts from EG 10 and EG12, Gona, Ethiopia. Note the evidence of several generations of flake removals on artefacts a, b and c and the presence of ripple marks from hard hammer impact evident on artefacts d-f (after Semaw, et al., 1997: 336).

Additionally, the fact that various core/chopper specimens exhibit ‘several generations of flake scars’ (Semaw, et al., 1997: 335), with many examples flaked around much of the circumference (Semaw, 2006: 57) (see Figure 4.4), suggests a capability for exploiting the conchoidal fracture properties of the raw material, which similarly implies that the Gona knappers were utilising hard hammer percussion with proficiency (Semaw, 2006: 58).

Hard hammer percussion is also evident at a number of sites that are of a similar age to Gona. For example, hammerstones excavated at Lokalalei 2C in the Lake Turkana basin, Kenya, display clear evidence of being used as percussive tools (Delagnes & Roche, 2005: 461). Indeed, Delagnes and Roche argue that the concentrated impact zones on the hammerstones indicates the hard hammer percussion technique was an established and stable motor habit by 2.34 million years ago (Delagnes & Roche, 2005: 461-462). Further robust evidence of the use of the hard hammer technique at this site is provided by refits from the lithic assemblage, with reduction sequences ranging from a few conjoined flakes to extended sequences consisting of nearly complete sets of up to 30 flake removals (Delagnes & Roche, 2005: 543; Roche, et al., 1999: 59).

Hard hammer percussion has also been identified at two sites dating to approximately 2.3my at Omo, Ethiopia: Omo 57 and Omo 123 (de la Torre, 2004b: 440, 441). Though fluvial deposits of natural quartz gravels contribute over half the Omo 57 assemblage, de la Torre proposes that clear evidence of purposive knapping can be demonstrated on other elements, such as the whole flakes, cores and flake fragments, which were originally deemed to be accidental waste products because of their small size (de la Torre, 2004b: 444). For example, the dorsal faces of many of the flakes (28 of 50 specimens) exhibit negative scarring from previous removals while also displaying a consistent direction of removal (predominantly unidirectional), which de la Torre views as indicative of a systematic knapping process rather than accidental, isolated removals (de la Torre, 2004b: 444). Patterns similar to these can also be identified in the Omo 123 assemblage; more than 50% of the 110 specimens of whole flakes display a single dorsal flake scar from previous removals, while 27.6% display two, 8.7% display three and 1.6% display four (de la Torre, 2004b: 447). As with Omo 57, the direction of the majority of the flake scars are unidirectional (see Figure 4.5). The overall pattern at Omo suggests hard hammer percussion was employed by hominids to remove a few flakes from small natural cores (de la Torre, 2004b: 448).

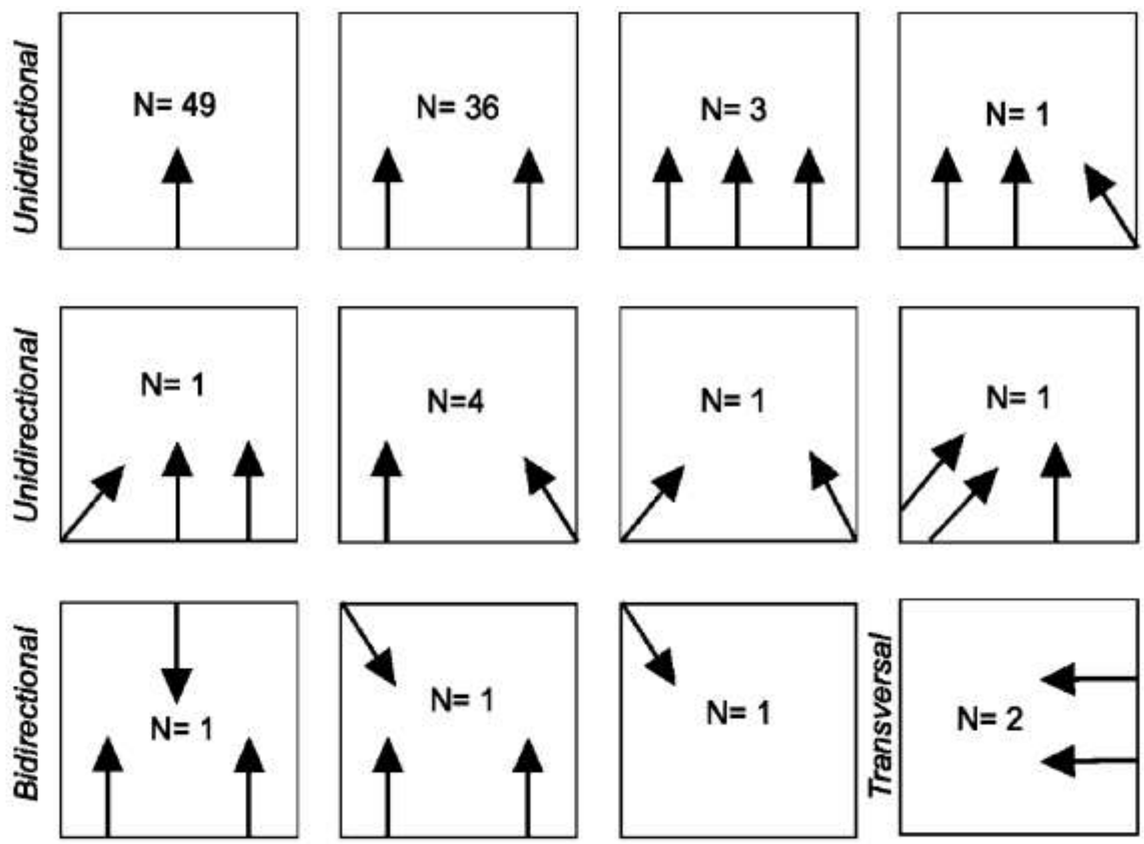

Figure 4.5: Diacritic schemes showing the direction of flake removals evident on the dorsal faces of flakes/flake fragments at Omo 123, Gona, Ethiopia. Note that the majority, some 95%, are unidirectional, following the removal direction of the flake/flake fragment itself, which suggests the repeated use of a single striking platform (after de la Torre, 2004b: 447).

The utilisation of hard hammer percussion is also evident from other Oldowan sites that occur later in the archaeological record. For example, the lower Bed I site of DK at

Olduvai Gorge, dated to 1.75 my (Leakey, 1971: 21), yielded evidence of the use of the hard hammer percussion technique in the form of hammerstones displaying zoned bruising/crushing on the extremities (Leakey, 1971: 37). The deep flake scars indicative of hard hammer percussion are present on various chopper specimens recovered (see Figure 4.6) (Leakey, 1971: 25).

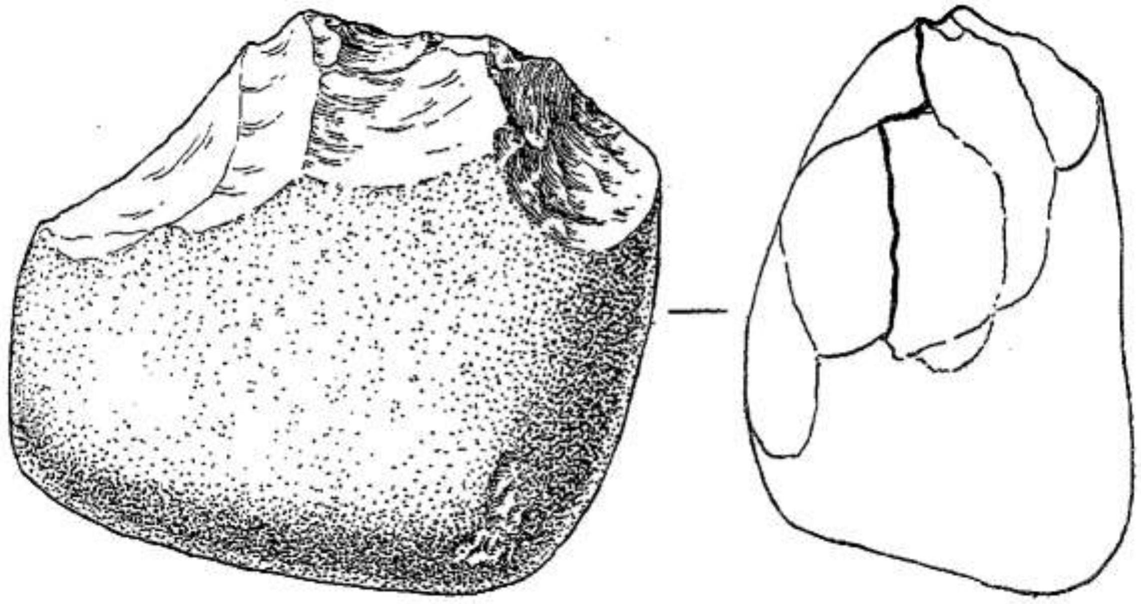

Figure 4.6: Side chopper from site DK at Olduvai Gorge. Note the deep flake scars indicating the use of hard hammer percussion (after Leakey, 1971).

The débitage element of the assemblage includes whole flakes with marked bulbs of percussion and striking platforms (Leakey, 1971: 37, 39). The use of the hard hammer technique is also evident at sites beyond Africa within this time frame. For example, the lithic assemblage from Dmanisi, Georgia (1.7-1.8my), presents abundant evidence of hard hammer use (Mgeladze, et al., 2011: 590). The lithic assemblage from this site is comparable to other African Oldowan locales, and includes cores and core-choppers with evidence of organised flaking via hard hammer percussion (see Figure 4.7) as well as a large quantity of flakes and flake-tools (Mgeladze, et al., 2011: 583, 587, 593)

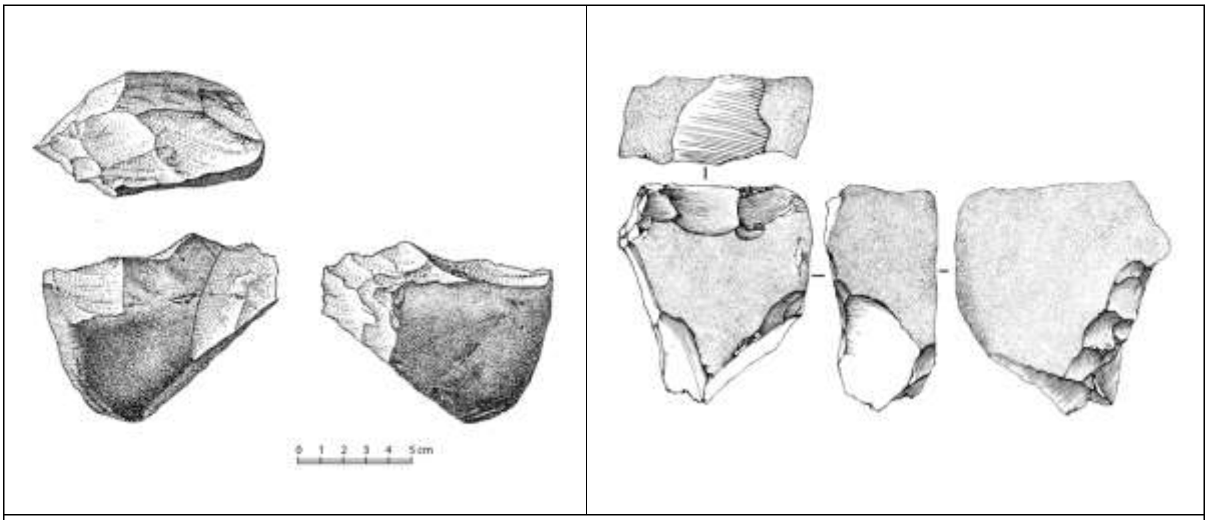

Figure 4.7: Early evidence of organised flaking via hard hammer percussion. Examples of a bifacially exploited chopper core from Dmanisi (left) and a core exhibiting multifacial orthogonal exploitation (right) (after Mgeladze, et al., 2011).

The archaeological evidence therefore suggests that hard hammer percussion is a technique that was capably utilised by hominids at an early stage and is associated with numerous sites within Oldowan time frames. Due to the nature of the archaeological evidence one cannot prove conclusively that hard hammer percussion was a behaviour that recurs in the *Homo* line from this time frame onwards. It remains a possibility that the technique was discovered and re-discovered by various populations of hominids, many of which were not ancestral to modern humans. Strong indications abound, however, that the hard hammer percussion technique came to be widely utilised in subsequent populations, leading to its eventual ubiquity in the *Homo* lineage. The technique continued to be used in the production of Oldowan-type tools as the dominant stone tool making behaviour until approximately 1.4 million years ago (Whiten, Schick, & Toth, 2009: 1). Beyond this, the hard hammer percussion technique recurs in the sense that it continues to be implicated in the production of subsequent complex technologies that emerge after c.1.4my, either as the sole technique employed, or as one technique applied alongside others.

The Levallois method, for example, represents a complex, sophisticated stone tool technology produced via an elaborate method, but which requires only hard hammer percussion in terms of technique (Chazan, 1997). The exclusive use of hard hammer percussion for the Levallois technique is posited from modern experimental replication of the method (Chazan, 1997: 724; Klein, 2009: 486), and also from refits of the method from lithic assemblages recovered archaeologically (Schlanger, 1996). Marjorie's core is such an example of a comprehensively refitted Levallois core recovered during excavations at the Maastricht-Belvédère quarry in southern Limburg, Netherlands (Schlanger, 1996: 231, 240). The core itself comprises 41 refitted flakes conjoined either to the core or each other (Schlanger, 1996: 240) and all were removed via hard hammer percussion. Blade production is another example of a complex method associated with the use of the hard hammer percussion technique. Archaeological evidence from two sites (GnJh-42 and GnJh-50) at the Kapthurin Formation, Kenya suggest that blade production dates to approximately 500kya (Johnson & McBrearty, 2009). The features used to identify the use of hard hammer percussion from this lithic assemblage include distinctive bulbs of percussion on blades together with negative scars on the cores (see Figure 4.8) (Johnson & McBrearty, 2009: 4). Experimental replication of blade tools also supports the view that blade production can be achieved using the hard hammer technique alone (Sollberger & Patterson, 1976: 518-521).

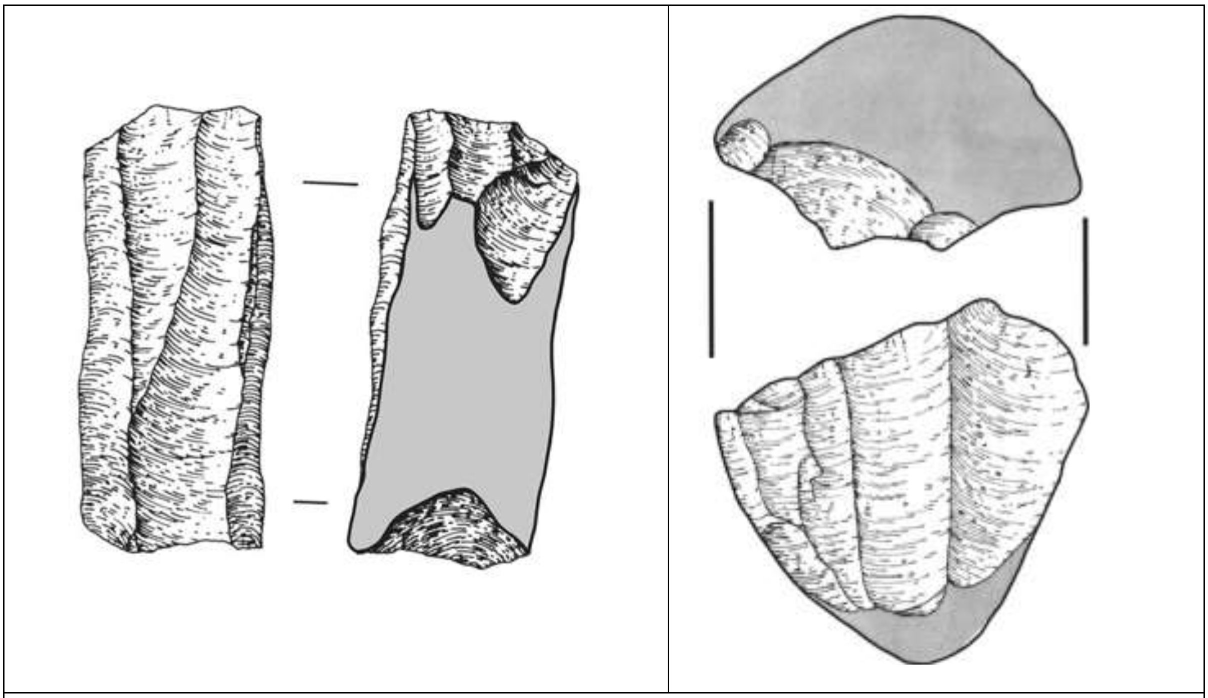

Figure 4.8: Blade production via hard hammer percussion. Lithic artefacts exhibiting the use of hard hammer percussion in blade production from the Kapthurin, Kenya (after Johnson & McBrearty, 2009: 4)

In other cases, the hard hammer percussion technique is employed alongside other techniques, typically to achieve certain aims at different knapping stages in order to meet an overall knapping goal. As Whittaker notes, hard hammer percussion is often employed as a '…starting point for many more refined tools' and is '…used to produce flake blanks and to rough out forms than can be finished by other techniques' (Whittaker, 1994: 85). In biface manufacture, for example, the more refined biface forms are typically associated with the soft hammer percussion technique, but the initial shaping of the core is achieved via hard-hammer percussion (see Figure 4.9).

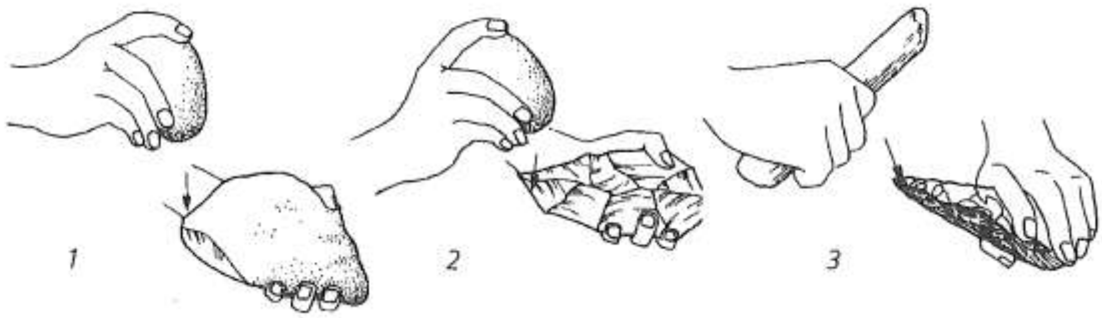

Figure 4.9: Illustration of the steps involved in the production of an Acheulean handaxe. Note that the hard hammer percussion technique is used in the initial shaping phases (steps 1 and 2, above), after which the soft-hammer percussion technique (step 3, above) is used to remove 'thinning' flakes (after Mithen, 1996: 118)

4.4.2. Recurrence of the Task Domain of Hard Hammer Percussion

Though one can surmise from the archaeological record that the hard hammer percussion technique is pervasive over time, the recurrence of the information-processing problems associated with its use also need to be considered. For the hard hammer percussion technique, the most likely source of variation in its use stems from the fracture properties of the raw material used. In one sense at least, one could argue that the use of hard hammer percussion depends upon certain fracture properties that are reliably present over time. As mentioned previously, the technique exploits the tendency of a raw material to fracture conchoidally under specific conditions. Conchoidal fracture refers to the way in which the force from a blow disperses through a material from the point of impact and spreads uniformly in a 'Hertzian cone' (See Figure 4.2) (Pelegrin, 2005: 24-25; Whittaker, 1994: 12). This phenomenon only occurs when a blow of suitable force is struck with a hammerstone that is near to, but not on, the edge of the core, and at an angle of no less than 90° (Pelegrin, 2005: 25). As a task, therefore, the hard hammer percussion technique always requires the delivery of a hammerstone blow on a viable striking platform within certain parameters that determine whether a fracture will be initiated.

The recurrence of the information-processing problems of the task domain of hard hammer percussion can be brought into question, however, when one considers that the predictability with which conchoidal fracture occurs can vary between raw material types:

> 'The predictability with which different raw materials break is extremely variable […] and severely limits the implementation of specific core production modes on some raw materials…' (Braun, Plummer, Ferraro, et al., 2009: 1606)

Here, then, is a potential obstacle to the notion that the information-processing problems of the hard hammer percussion technique reliably recur over time, and it is one that stems from factors relating to the environment in which the task is performed. If the substrates on which the technique is applied is variable, to the point that it does not fracture predictably from one knapping episode to another, then one could argue that the task domain has no reliably recurring information-processing problems. One can address this problem by noting that it implicitly assumes that the various raw material types utilised by our ancestors were randomly selected, to the extent that the variation in their fracture properties was a consistent feature of the technique's use. This assumption can be challenged based on archaeological evidence for raw material selectivity in stone tool production.

The preferential selection of raw materials for knapping is evident from the earliest manifestations of stone tool production in Oldowan contexts at such sites as Gona, Ethiopia (Stout, Quade, Semaw, Rogers, & Levin, 2005: 377-378), Lokalalei 2C, Kenya (Harmand, 2009: 94), and Kanjera South, Kenya (Braun, Plummer, Ferraro, et al., 2009: 1612). Typically, raw material selection at these early sites is based on its initial morphology (e.g., preferentially core selection for cores with naturally advantageous platforms) (Barsky, 2009: 44), which suggests a degree of appreciation of raw material fracture properties. In addition to selecting cores with naturally serviceable platforms, hominids also tested out raw materials from certain locations before transporting the best pieces to activity areas; this type of behaviour is proposed based on the observation that sites exist where only certain stages of the flaking process appear to be present (Toth, 1985: 114-115). Fracture predictability has been posited as a major factor guiding raw material selection (Stout, et al., 2005), a hypothesis supported by subsequent knapping experiments which highlighted the different fracture qualities of selected and non-selected stone (Roche, et al., 2009: 138). Conversely, while not discounting fracture predictability as a factor, others have suggested that raw material selection may have been guided by other aspects, such as the durability of sharp edges on flakes (Braun, Plummer, Ferraro, et al., 2009: 1612).

Overall, there are adequate grounds to conclude that the predictability of fracture properties did indeed constitute a viable criterion for raw material selection (albeit one among other possible criteria). Arguably, therefore, the problem of raw material variability as a source of variable information-processing problems in stone tool producing behaviours can be dismissed. If behavioural strategies were being adopted at an early stage which ensured that raw materials with 'predictable' fracture properties were utilised more frequently than other raw material types in instances where the hard hammer percussion technique was utilised, then one could argue an ongoing bias would have been present ensuring exposure to a more specific/narrow set of problems associated with raw materials that fracture with this higher degree of predictability. The apparent problem of variability in raw material fracture properties is therefore one that is mediated by such preferential selection over time.

4.5. Fitness consequences of the Hard Hammer Percussion Technique

An assessment of the fitness consequences associated with the hard hammer percussion technique would ideally begin at the point of emergence and then trace the techniques through the various archaeological contexts in which they occur, cataloguing the fitness consequences at each juncture (as far as they can be gleaned from the archaeological data available). The prospect of achieving this, however, is complicated by the fact that, as stone tool producing behaviours become more complex over time, it becomes difficult to conclusively attribute fitness consequences to a technique alone, as opposed to a technique used in combination with a given method. As argued above, the hard hammer percussion technique remains prominent in the application of various methods of stone tool production over time. It therefore remains necessary in terms of solving the adaptive problems associated with stone tool production methods. However, it is not sufficient to attain whatever benefits accompany a given method of stone tool production. Therefore, the use of the hard hammer percussion technique is not, in itself, sufficient to produce Levallois flakes or bifaces – it needs to be applied in conjunction with a method of tool production. Below, I will therefore focus on the earliest contexts where the hard hammer percussion technique is visible, prior to the emergence of more complex stone tool production methods.

The archaeological record suggests various fitness benefits were associated with the use of the hard hammer percussion technique. Evidence from Oldowan sites, for example, suggest the technique was implicated in the opening a plethora of new subsistence niches (Lewin & Foley, 2004: 315). Evidence supporting this claim can be gleaned from the artefacts themselves, in tandem with other relevant contextual evidence (e.g., faunal remains).

Evidence from faunal remains from Oldowan contexts has provided compelling evidence for the butchery of carcasses (i.e. the dismembering/de-fleshing of a carcass for meat and the breaking of bones to extract marrow) (Bunn, 1981; Toth & Schick, 2009: 293). For example, diagnostic cut marks and fracture patterns on animal bones have led some archaeologists to suggest that meat consumption featured in hominid subsistence activities as early as 2.5million years ago (Ambrose, 2001: 1749; Toth & Schick, 2007: 1943). The hard hammer percussion technique would have enabled such behaviours through the production of numerous sharp edges. Roche *et al*, for example, state the following:

> 'If […] early hominin carnivory involved regular interactions with larger carcasses than those consumed by chimpanzees, it follows that being able to knap and use stone tools as aids to butchery would have been a skill with positive fitness consequences.' (Roche, et al., 2009: 142)

Indeed, modern experiments investigating the functional efficiency of Oldowan tools in carcass processing have also demonstrated that they are effective for butchering anything from small mammals to elephants (Toth & Schick, 2007: 1951).

Evidence from use-wear analysis suggests that carcass processing by no means exhausts the uses to which hominids put stone tools. The examination of use-wear polishes on stone flakes indicate that Oldowan tools were used on 'soft plant materials' (such as grasses or reeds) as well as for cutting and scraping wood (Keeley & Toth, 1981: 465) [17]. This hints at a much wider range of fitness benefits linked to hard hammer percussion which may have been rendered archaeologically invisible due to the prevalent preservation biases against organic materials (Roche, et al., 2009: 142).

What can be said with confidence, however, is that even in the earliest archaeological contexts, hard hammer percussion allowed the exploitation of multiple subsistence niches, producing ‘a wide range of variation in the behavioural, adaptive, and technological patterns depending upon local circumstances’ (Toth, 1985: 118). Some of these niches (such as processing the carcasses of large animals) would have previously been either inaccessible or prohibitively expensive in terms of energetic investment. Lewin and Foley go as far as to describe the production of a cutting edge as ‘a technological and economic revolution’ in terms of the ‘multifarious functions they perform’ (i.e. slicing and scraping) and their potential for use in making other tools (e.g. shaping digging sticks from wood) (2004: 308-309, 315).

In addition to the evidence considered above, one can make inferences regarding the fitness consequences attached to hard hammer percussion from both the energetic investments associated with its adoption and the attendant risks accompanying at least one of the niches that stone tool use allowed hominins to exploit. The production of stone tools via hard hammer percussion in Oldowan contexts required energetic investment in at least two areas. The first is the investment of time and effort in acquiring the necessary

[17] As Lewin and Foley note, due to the nature of the raw material used, use wear analysis is not always straightforward for Oldowan artefacts: ‘Direct evidence of the application of an ancient tool is difficult to obtain, not least because the coarse nature of lava flakes does not sustain clear signals of the material with which it has been in contact.’ (2004: 315). In addition, as Roche *et al* note that Oldowan flakes may have enjoyed a relatively brief use-life before being replaced, which would reduce the opportunities for the formation of diagnostic use wear traces (Roche, et al., 2009: 143). Despite this, successful use wear analyses have been conducted on ancient tools in some instances (cf. Keeley & Toth, 1981).

aptitudes of hard hammer percussion to successfully knap stone (these skills would have been essential in the production of Oldowan tools which, despite their deceptively primitive appearance, require sophisticated bi-manual control (Toth & Schick, 2009: 293)). The second investment in terms of time and effort concerns the location, transport, and retention of the raw materials necessary for stone tool production. Evidence of the transport of raw materials across palaeolandscapes is present at numerous Oldowan sites, with some materials being transported up to 20km from their origin (Blumenschine, et al., 2008; Braun, Harris, et al., 2009; Braun, et al., 2008; Braun, Plummer, Ditchfield, Bishop, & Ferraro, 2009; Goldman-Neuman & Hovers, 2009; Harmand, 2009; Hay, 1976; Negash, Shackley, & Alene, 2006; Piperno, Collina, Gallotti, Raynal, & Kieffer, 2009; Schick, 1987; Stout, et al., 2005; Toth, 1982; cited in Toth & Schick, 2009: 292).

Both of these factors indicate that the production/use of stone tools played an important role in early subsistence behaviours. This claim is bolstered further by evidence of the testing of raw material quality at source (through removing experimental flakes) and the reduction of cores prior to transport, which suggests that, rather than being an opportunistic behaviour, sophisticated planning and retention strategies were being employed as early as 2.6 million years ago to ensure continued access to stone tools across various landscapes (Toth, et al., 2006: 215). When paired with the evidence from faunal remains and use wear, it is difficult to conclude that such investment of time and energy would be present in the absence of any concomitant benefits in terms of fitness.

Finally, the potentially maladaptive consequences associated with the niches accessed through the use of hard hammer percussion, particularly the increased the risk of becoming a victim of predation, might lead one to infer that the subsistence benefits justified the risks involved. As Roche *et al* note, hominids entering the carnivory niche in the Plio-pleistocene would be competing with a wide array of 'large-bodied felids, hyaenids, canids and crocodilians' (Roche, et al., 2009: 136). This assertion is supported to an extent by evidence of multiple sources of damage evidenced in faunal remains (Klein, 2009: 267; Potts & Shipman, 1981: 579). For example, Potts and Shipman document damage to animal bones where stone tool cut marks are overscored by tooth marks (see Figure 4.10), implying that the bone was processed with stone tools and subsequently gnawed by a carnivore (1981: 577).

The specific nature of this competition (and therefore the attendant risk) has been the source of some debate among archaeologists, particularly with reference to how hominids secured access to a carcass. Toth and Schick note that there are two main models regarding hominid meat procurement (2009: 292). On one view, hominids would have had access to a large part of the carcass through 'confrontational scavenging' (i.e. where co-ordinated action is used to scare a predator away from a fresh kill), or through active hunting of prey (Bunn, 1983; Bunn & Kroll, 1986; Domínguez-Rodrigo, 2009; Domínguez-Rodrigo, Egeland, & Barba, 2007; Pickering & Domínguez-Rodrigo, 2006; Pickering, Domínguez-Rodrigo, Egeland, & Brain, 2007; cited in Toth & Schick, 2009: 292).

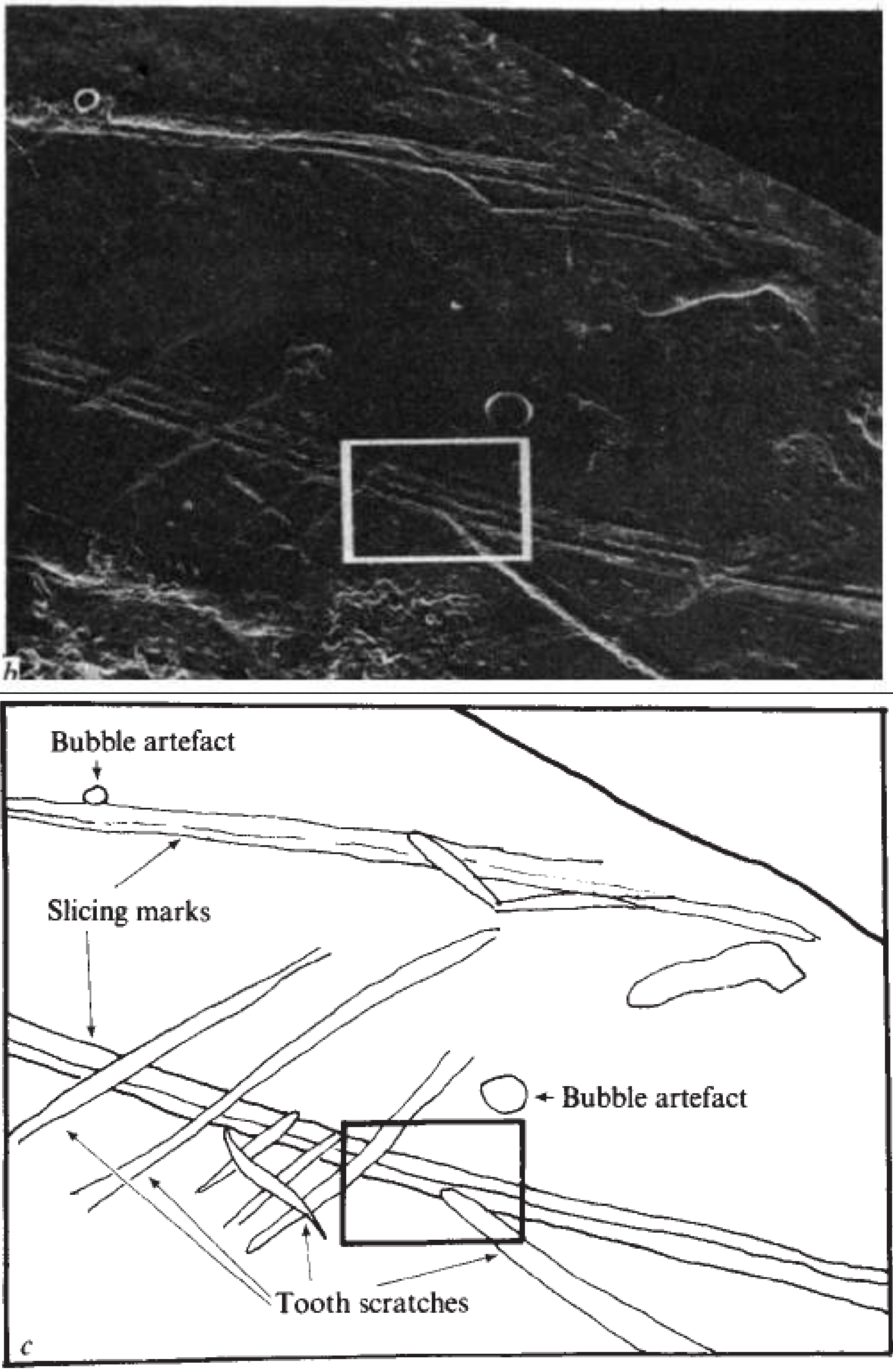

Figure 4.10: Micrograph of an equid tibia from Olduvai Gorge (top) and a sketched interpretation of the marks (bottom). Potts and Shipman developed a method of distinguishing tooth marks and cut marks, and on this basis argue that damage from gnawing in this example occured after cut marks made with stone tools; this is one of three examples from a sample size of 75 bone surfaces where gnawing and cut marks intersect (after Potts & Shipman, 1981).

On another view, hominid scavenging would have been more peripheral; only certain parts of the carcass would be accessed via ‘marginal’ or ‘passive’ scavenging (i.e. by scavenging the leftovers of a predator’s kill) (Blumenschine, 1986, 1989; Blumenschine & Pobiner, 2006; cited in Toth & Schick, 2009: 292).

Of course, it is feasible that both methods were employed in Plio-pleistocene environments, either by different groups with different foraging strategies, or by the same group in response to the specific ecological circumstances (for example, the decision to adopt a particular scavenging tactic may depend on the size and number of carnivores to be confronted). The important point, as Toth and Schick note, is that:

> ‘Consistent acquisition of such food sources would have placed them [hominids] in more direct competition with active predators and scavengers and likely increased their risk factors from predation as well.’ (2009: 294)

One could surmise that the maladaptive consequences of entering a niche that increases the risk of encountering predators must be offset by significant benefits in terms of fitness. Such benefits may be found in the procurement of meat and marrow, which represent ‘high-quality’ food sources (Ambrose, 2001: 1750).

4.6. Definition of the Soft Hammer Percussion Technique

As the name implies, the soft hammer percussion technique involves the striking of flakes from a core with a ‘soft’ hammer, most commonly assumed to be a billet of antler, wood or bone (Mithen, 1999b: 393; Whittaker, 1994: 180). Some archaeologists, however, note that some 'soft' stone materials (such as weathered limestone or fine-grained sandstone or cortical flint) can also be used in the application of the technique to produce the same effect as a billet (Hayden & Hutchings, 1989: 239; Wenban-Smith, 1999: 384).

In addition to utilising a different type of percussor, soft hammer percussion is distinctive from hard hammer percussion in terms of the way a blow is delivered. The use of the soft hammer percussion technique involves delivering blows to the 'edge' of the raw material, rather than on a flat striking platform (a requirement that maintains regardless of whether a billet or soft stone is used as the percussor) (Whittaker, 1994: 191, 196) (see Figure 4.11).

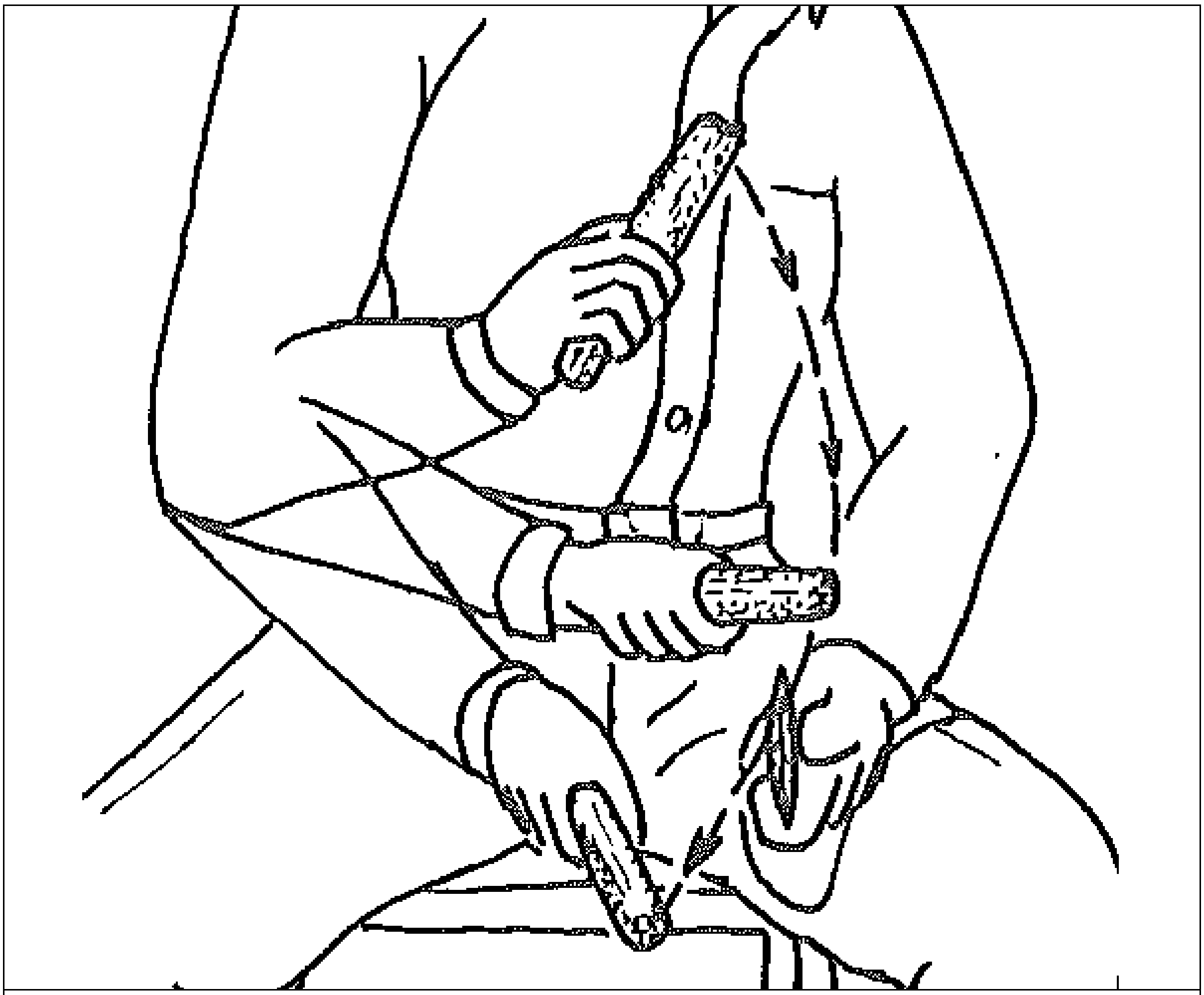

Figure 4.11: An illustration of soft hammer percussion. Note the use of a wood/bone/antler percussor (right hand) and the location of a typical soft hammer strike on the edge of the pre-prepared core (after Whittaker, 1994: 183).

Soft hammer strikes also need to be delivered with much more force (Whittaker, 1994: 187) and at 'quite different angles' compared to hard-hammer percussion (Mithen, 1999b: 393). Whereas the hard hammer percussion technique requires blow angles of less than 90°, in the case of soft hammer percussion a blow angle of 130-150° is often required (see Figure 4.12) (Whittaker, 1994: 187, 191).

Figure 4.12: Illustration of a soft hammer percussion striking platform. The soft hammer technique utilises the edge of the core as the striking platform. In the above example, the arrow indicates the ideal striking point for a soft hammer blow (after Whittaker, 1994: 192).

The soft hammer percussion technique is also distinctive in terms of morphology of the resulting flakes. Whittaker proposes that this is due to the soft hammer compressing slightly when a blow is applied, which causes the force of the blow to 'spread out and transmitted more slowly and evenly' through the material (Whittaker, 1994: 185). As a result, this technique is particularly useful for 'removing large, relatively flat and thin flakes with small bulbs of percussion' and is therefore often implicated in the thinning/shaping stages of biface manufacture (Mithen, 1999b: 393; Whittaker, 1994: 185).

Any reference to the soft hammer percussion technique below will refer to the use of a soft hammer billet or soft hammerstone to apply directed, co-ordinated blows to remove flakes from the edge of a core.

4.6.1. Archaeological Identification

The soft hammer percussion technique can be identified archaeologically in three main ways. The first is through the recovery of the billets used in the application of the soft hammer percussion technique (Whittaker, 1994: 180). Whittaker, for example, proposes that soft hammer billets can be distinguished from naturally occurring wood, antler and bone fragments by '…the distinctive faceting wear, the tiny flakes embedded in the facets, and the polish that develops where the hand grips them' (Whittaker, 1994: 182). The Middle Pleistocene site of Boxgrove, located in West Sussex, England, provides a good example of a site where billets of bone and antler were recovered in association with lithic scatters (Wenban-Smith, 1999). However, the archaeological recovery of soft hammer billets is perhaps the most serendipitous method of identifying soft hammer percussion. If billets were used repeatedly to make a number of tools one may surmise that discard would have been a rare event. Indeed, when discard did occur it would need to be in a context favourable to the preservation of the organic material used for billets.

A second method for identifying the soft hammer percussion technique archaeologically concerns the distinctive tool types that are produced via its application (Whittaker, 1994: 180). In the case of biface manufacture, for example, it is possible to make distinctions between bifaces produced via hard or soft hammer percussion. Modern replication experiments suggest that the manufacture of certain 'crude' biface forms, which are typically (though not exclusively) associated with earlier archaeological contexts, can be attributed to hard hammer percussion based on the fact that fewer flakes are removed, less symmetry is evident, and the final form is comparatively thick (Klein, 2009: 379; Toth & Schick, 2007: 1956) (see Figure 4.13).

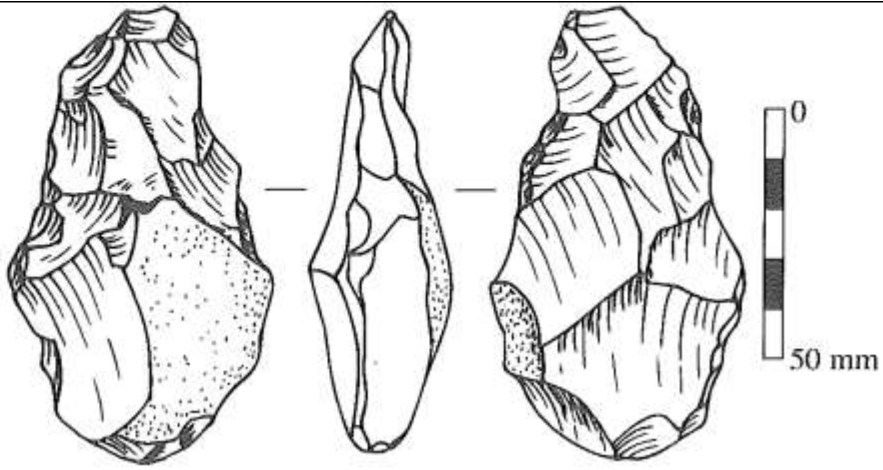

Figure 4.13: An example of an early Acheulean biface (1.5my old approximately) from Sterkfontein, South Africa. Note the deep flake scars, which indicate the use of hard hammer percussion in the production process (after Klein, 2009: 389)

In contrast, soft hammer percussion produces shallow and flat flake scars, as exhibited by later examples; these 'refined' bifaces also tend to be thinner, more extensively trimmed, and display various forms of symmetry (Klein, 2009: 379; Toth & Schick, 2007: 1956) (see Figure 4.14).

The third way that the soft hammer percussion technique can be identified archaeologically concerns the distinctive flake removals/debitage produced in its application. This may involve a simple examination of the scars on the exterior surface of flakes to try and infer the use of soft hammer percussion for the preceding removals. Alternatively, detailed metrical analysis of flake features associated with the fracture mechanics of soft hammer removals can be carried out. To date, much of the work in this area has concern experimental replication of the soft hammer percussion technique to try and identify the distinctive features it produces on flakes (particularly when compared with hard hammer flakes).

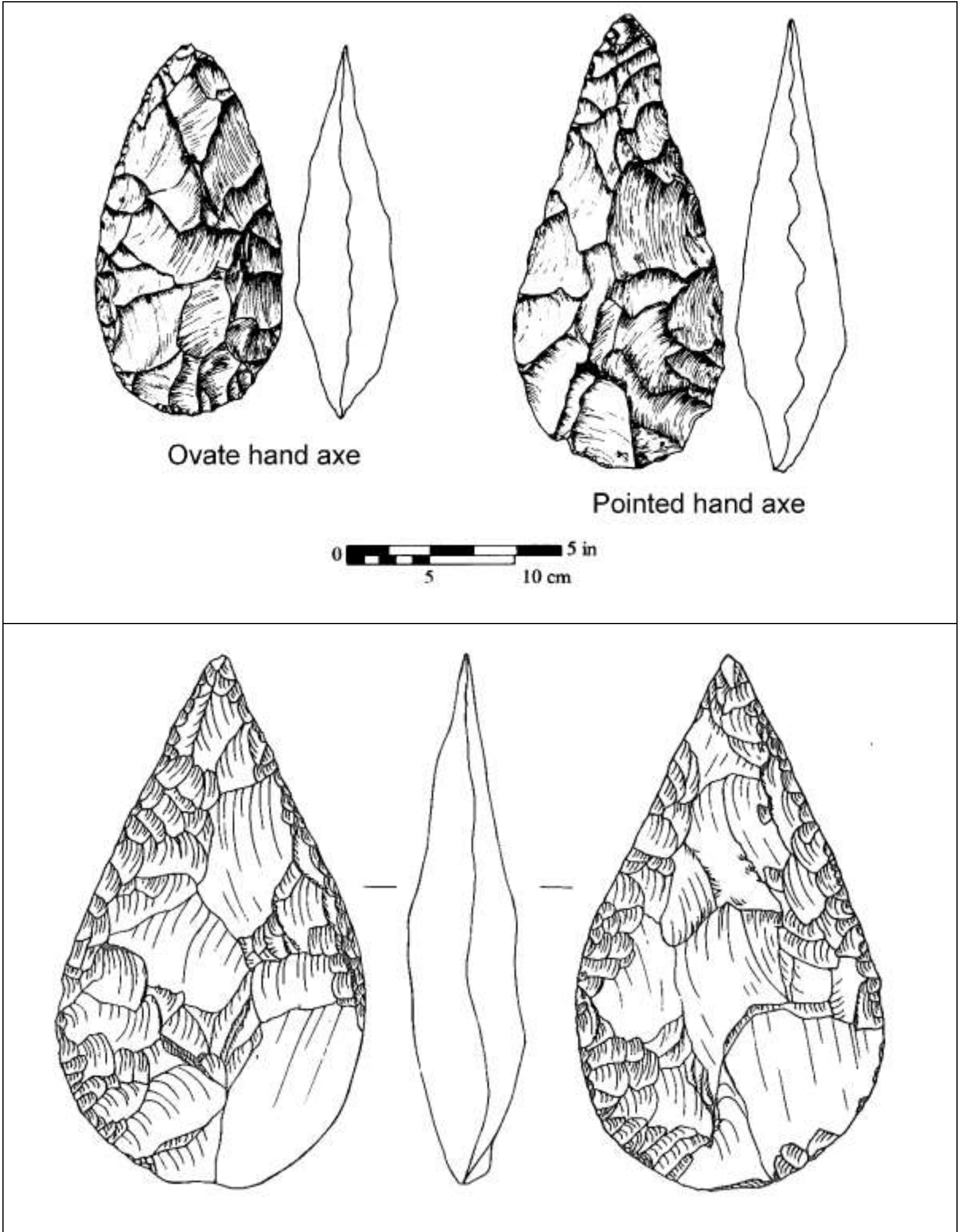

Figure 4.14: An example of a later, 'refined' bifacial tools exhibiting shallow flake scars typical of the use of the soft hammer percussion technique. Top: two 400,000 years old examples from Bouri, Middle Awash Valley, Ethiopia (after Toth & Schick, 2007: 1956). Bottom: a 600ky old approximately) from Kathu Pan, South Africa (after Klein, 2009: 389).

For example, soft hammer flakes are typically described as quite large, flat and thin in terms of shape, with shallow or diffuse bulbs of percussion (Crabtree, 1970: 148; Whittaker, 1994: 185) (see Figure 4.15), with an interior platform displaying a prominent 'lip' feature and a 'curved' overall shape (Newcomer, 1971: 88; Whittaker, 1994: 187).

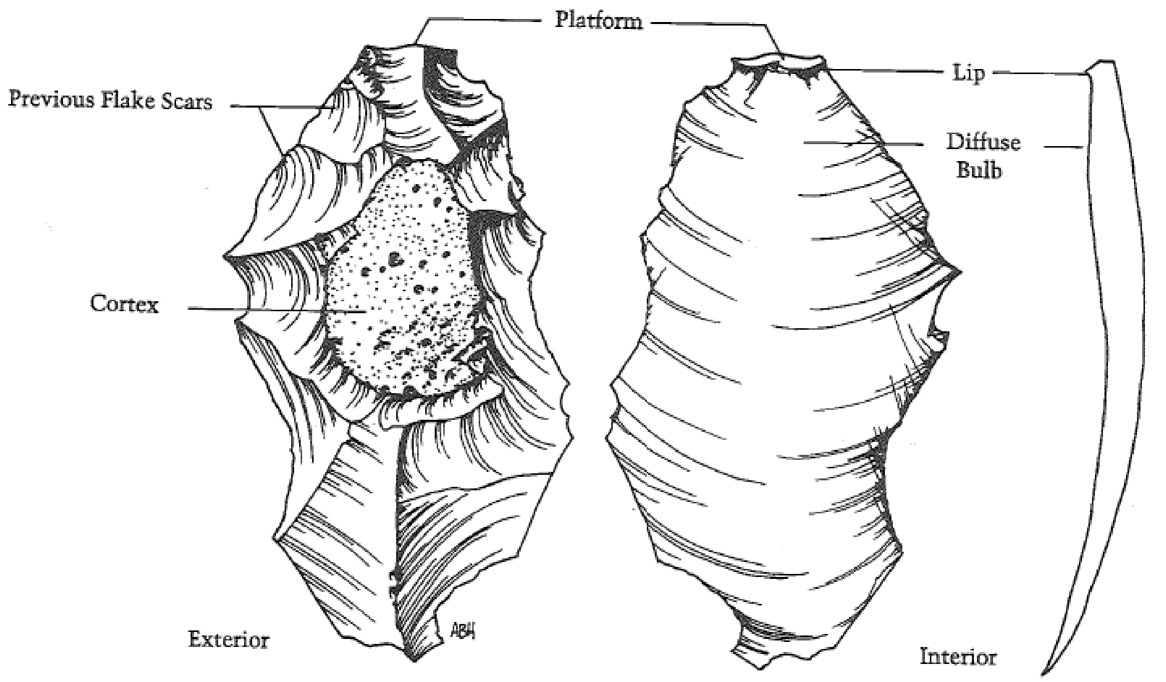

Figure 4.15: A typical soft hammer percussion flake. Detailed diagram illustrating the distinctive features and dimensions of a flake removed via soft-hammer percussion (after Whittaker, 1994).

While also citing the above features as indicators of soft hammer flaking, Hayden and Hutchings further propose that a '…lack of crushing under the point of impact, lack of point impact features, and small platform area in relation to flake size' are also evident in flakes removed with a billet (Hayden & Hutchings, 1989: 253). Similarly, Wenban-Smith, in providing a summary of soft hammer percussion experimental research, notes that a general consensus was reached by the mid 1980's that soft hammer percussion flakes have vague points/cones of percussion, discernible lip features on the striking platform, diffuse bulbs of percussion and conchoidal fracture marks that are comparatively indistinct (Wenban-Smith, 1999: 388). Figure 4.16 provides an illustration of the main differences between hard and soft hammer flake removals, though it should be noted that these criteria cannot be used to distinguish soft stone from soft organic billet removals.

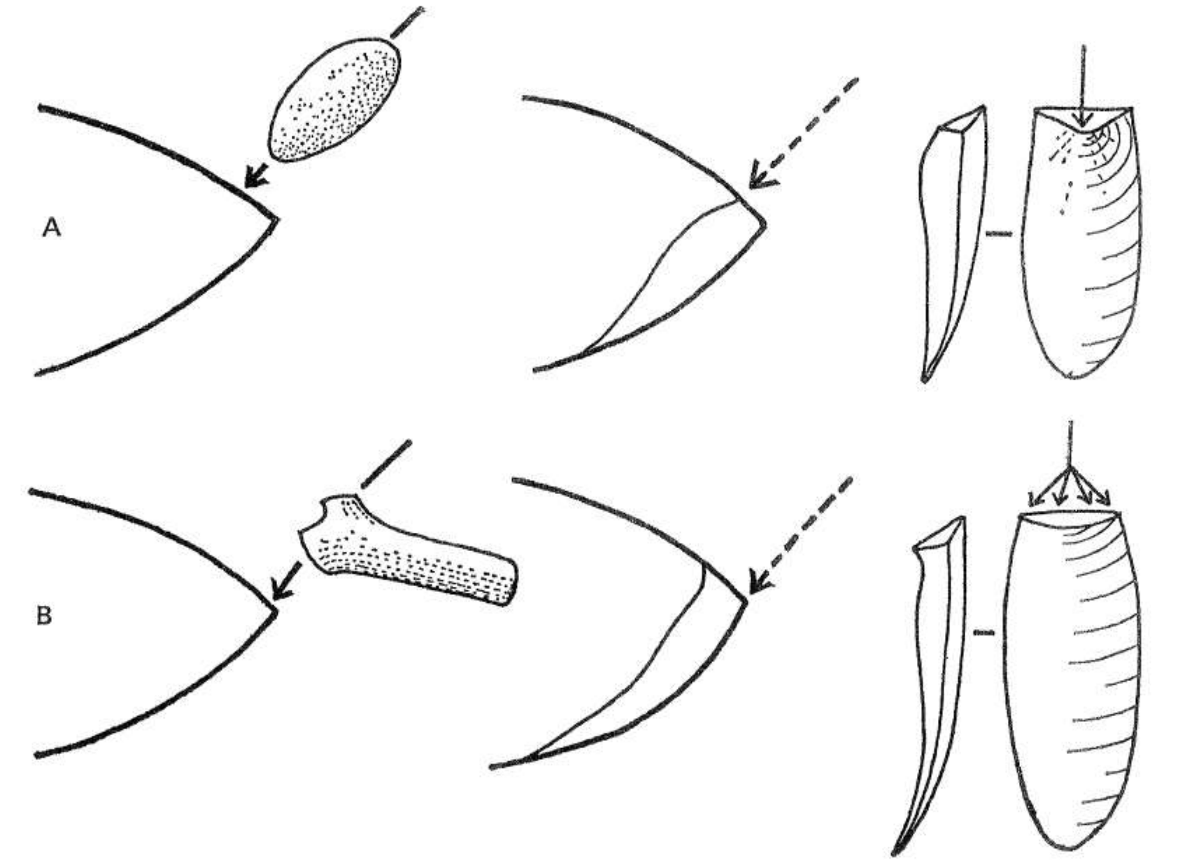

Figure 4.16: The differences between hard hammer (a) and soft hammer (b) percussion. Note the different point of the hammer strike (left), the different effects of the two flake removals on core morphology (middle) and the distinctive shape/features of the respective flakes (right) (after Newcomer, 1971: 88).

As noted by Wenban-Smith (1999: 388), experiments conducted by Ohnuma and Bergman (1982) resulted in a failure to distinguish between soft stone flakes and antler flakes where sets of flakes were examined to try and identify the hardness of percussors.

Despite the apparent consensus outlined above, doubts have been raised by other researchers regarding the degree to which such features can be conclusively attributed to individual flakes produced via soft hammer percussion. Bradley and Sampson (1986), for example, propose that the mode of flake removal is more relevant in determining flake morphologies than the kind of percussor used. Rather than hard and soft hammer removals creating distinctive flake types, they argue that flake attributes result from focusing blows on 'marginal' and 'non-marginal' areas (Bradley & Sampson, 1986: 43). 'Marginal' blows therefore produce the attributes typically associated with soft hammer percussion, regardless of whether a soft or hard hammer is used. Controlled experiments conducted by Pelcin (Pelcin, 1997a) which isolated hard and soft hammer percussors as variables counter this view to an extent. Pelcin's results suggest that soft hammer percussors reliably produce longer and thinner flakes compared to hard hammer percussors (Pelcin, 1997a: 620).

However, it should be noted that Pelcin did not attempt to compare marginal and non-marginal removals specifically. The focus of his experiment design was to compare soft and hard hammer removals while all other variables (i.e., blow strength, blow angle, and the exterior platform angle presented by the core) were held constant. It remains feasible, therefore, that the mode of removal may influence flake morphology more than percussor type, particularly when variability in core morphology and blow attributes (force, angle etc…) are taken into consideration (Cotterell & Kamminga, 1987; Dibble & Pelcin, 1995; Dibble & Rezek, 2009; Pelcin, 1997a; Pelcin, 1997b).

Others argue that the degree of confidence with which different percussors can be identified can be bolstered through the use of debitage signatures (Andrefsky, 2009: 81), with the distinctive features typically encountered in soft hammer flake assemblages occurring in higher frequencies than in assemblages produced via hard hammer percussion (Whittaker, 1994: 187). Wenban-Smith, for example, provides a robust challenge to Bradley and Sampson's emphasis on flaking modes by advocating a 'unit-based' approach to examine whether different percussor types are discernible based on debitage attributes (1999: 384). Experimental reproductions using a variety of percussors were conducted (i.e., organic percussors of antler/bone, soft-stone percussors of cortical flint, and hard percussors of rolled flint/quartzite), with subsequent analysis incorporating the total flake assemblage of each knapping episode (Wenban-Smith, 1999: 389-390). Contrary to Bradley and Sampson, Wenban-Smith proposes that percussor type, rather than the mode of flaking, affects various attributes on the flakes, and that it is possible to distinguish between assemblages produced via soft billet, soft stone, and hard hammer percussion (1999: 392). Wenban-Smith's conclusions are further bolstered by the fact that, based on the discriminant analysis conducted at Boxgrove, it was possible to successfully identify unknown percussors (Wenban-Smith, 1999: 393). However, it should be noted that, due to the focus on complete debitage episodes, this approach is highly contingent on factors of preservation and is not universally applicable as a result.

4.7. Recurrence of the Soft Hammer Percussion Technique

As with hard hammer percussion, the soft hammer percussion technique similarly needs to be considered from two perspectives to examine whether it can be viewed as recurrent in the sense required by the methodology of Evolutionary Psychology. Again, this necessitates a consideration of the archaeological occurrence of the technique, which incorporates evidence of its antiquity alongside a consideration of the extent to which the technique recurs over prehistory. Secondly, it requires a consideration of factors that might introduce variability into the task domain over time.

4.7.1. Archaeological Occurrence

In terms of antiquity the archaeological evidence provides strong indications that the soft hammer percussion technique emerged within the kinds of time frames cited by evolutionary psychologists. Hayden, for example, proposes that true 'billet worked bifaces' emerge at approximately 1million years (Hayden, 1989: 7). In terms of specific examples, some archaeologists propose that the shallow, flat flake scars evident on some bifaces dating to 600-400ky can provide a basis for inferring the use of the soft hammer percussion technique (Klein, 2009: 379; Toth & Schick, 2007: 1956) (see Figure 4.14).

Beyond inferences based on biface morphologies and flake scars, some sites have yielded more comprehensive data, allowing the examination of lithic scatters resulting from handaxe manufacture via soft hammer percussion. For instance, the site of Boxgrove presents a good example of the use of soft hammer percussion for handaxe manufacture. Exceptional preservation conditions at this site allowed the examination of 'essentially undisturbed knapping debitage' (Wenban-Smith, 1999: 384). Significant portions of the lithic scatters were attributed to soft hammer percussion as a result of thorough, 'unit-based' analyses (Wenban-Smith, 1999: 393). With sedimentary dating at this site suggesting an age range of 524,000 – 420,000 bp (Roberts & Parfitt, 1999: xix), this lends further support to the view that percussive behaviours utilising soft hammer stones/billets merit consideration from an evolutionary psychological perspective.

Unit 4c (Quarry 1, Area A), for example, consists of five 'finished' bifacial tools together with associated waste/debitage (see Figure 4.17) (Austin, Bergman, Roberts, & Wilhelmsen, 1999: 315).

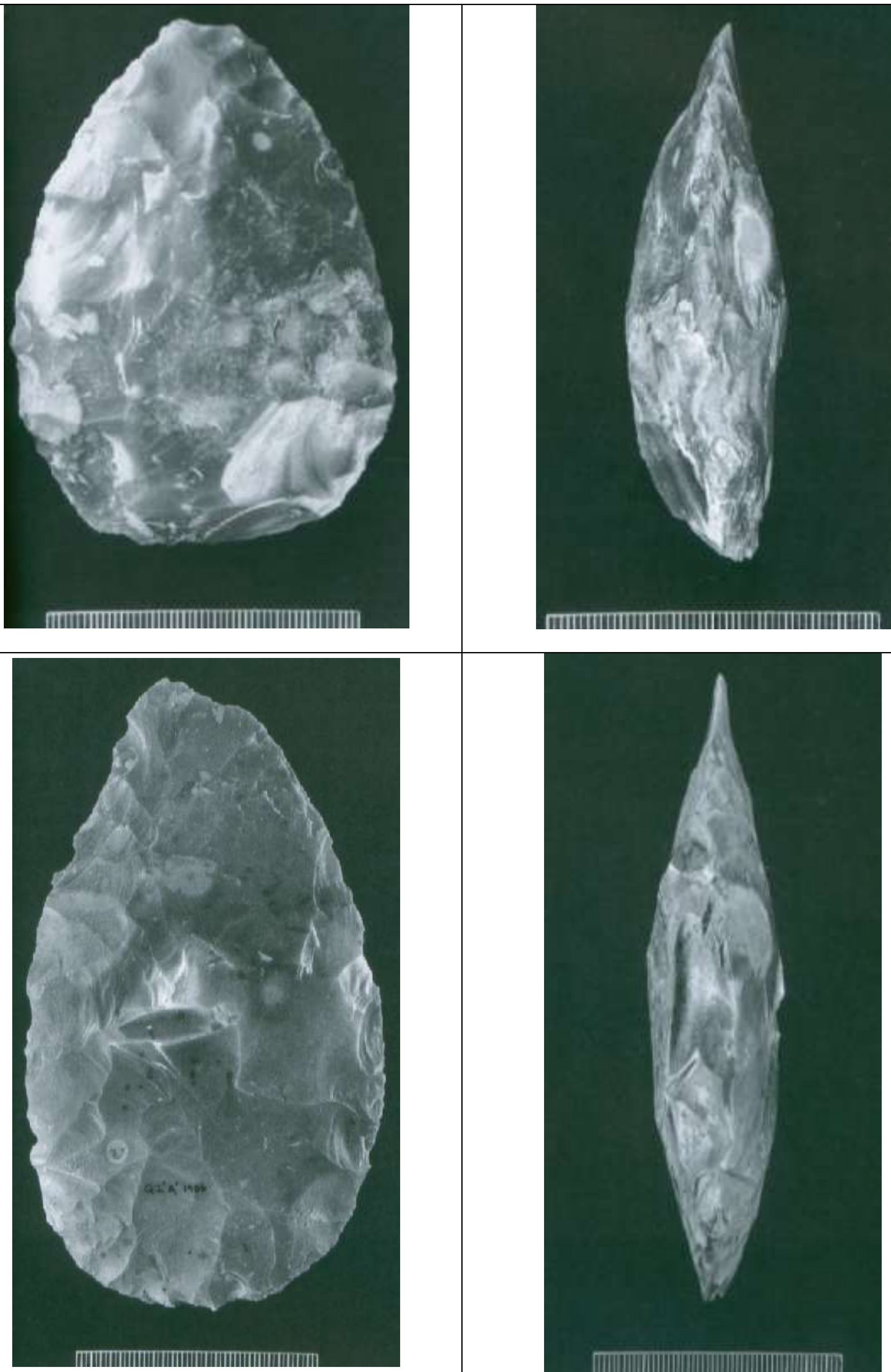

Figure 4.17: Handaxes from Boxgrove Unit 4c (Q1/A1). Two examples (top and bottom) of handaxes recovered from Unit 4c (Q1/A1) at Boxgrove bearing evidence of soft hammer percussion removals (after Austin, et al., 1999: 323, 325).

The assemblage consists largely of pieces smaller than 20mm in length (86% of the total assemblage), though from the analysis of 317 pieces that exceed 20mm the authors make a number of conclusions. With reference to the work of Newcomer (1971), they suggest that flakes from all stages of handaxe manufacture are represented (i.e., roughing out, thinning and finishing), that the proportions of these different flakes indicate the assemblage does not represent a complete reduction sequence, and that the soft hammer percussion technique is the dominant technique employed (Austin, et al., 1999: 318). The attribution of soft hammer percussion in this context was gleaned from the identification of thinning and finishing flakes (Austin, et al., 1999: 322). Though refitting was possible for 31.2% of the 317 pieces longer than 20mm, the maximum number of flakes in the refits was 4 and no flakes refitted to the handaxes recovered, indicating that only part of the reduction sequence is represented (Austin, et al., 1999: 319-320)

At Unit 4b, a ‘small and extremely dense knapping scatter’ was recorded (Austin, et al., 1999: 322). The recovered assemblage consisted of a total of 1715 pieces over 5mm in length (Austin, et al., 1999: 322). As with Unit 4c, the scatter does not represent a complete reduction sequence, though it differs from Unit 4c in that only flakes the latter stages of handaxe manufacture (i.e., thinning and finishing) are present (Austin, et al., 1999: 329). This, Austin *et al* argue, indicates that the scatter was produced via the soft hammer percussion technique alone: ‘None of the flakes showed evidence of the use of a hard hammer, all being of typical soft hammer production or marginal flaking mode…’ (1999: 335). Refitting of the assemblage bolsters this view. Of 198 flake fragments 48% (96 in total) were refitted; though the majority of these refits were between 2 and 4 flakes only, two examples of large refits (21 and 24 flakes) present good evidence of soft hammer percussion being used to engender a sequence of flake removals (Austin, et al., 1999: 335).

Beyond the earliest contexts where the use of the soft hammer percussion technique can be gleaned, archaeological evidence also indicates that it was employed subsequently over large spans of time, and over large geographic areas (Hayden, 1989: 12; Klein, 2009: 372). As Toth and Schick observe, the technique is also commonly found in Middle Palaeolithic (Mousterian) industries and Middle Stone age industries in sites spanning Europe, the Near East, and Africa between 250,000-30,000 years ago (2007: 1957-1958). The soft hammer percussion technique is also identifiable in the technologies of the Upper Palaeolithic in the Near East, North Africa and Western Europe (Soriano, Villa, & Wadley, 2007: 682) as well as in some Palaeo-Indian and American archaic contexts (Hayden, 1989: 12-13).

Despite evidence above, however, one can point to two main factors indicating that a degree of caution is necessary in proposing a robust form of recurrence for the soft hammer percussion technique. Firstly, as touched on above, issues remain regarding the degree of confidence with which the technique can be conclusively identified archaeologically. Clearly, the soft hammer percussion technique can be identified with a high degree of certainty at sites such as Boxgrove. But this identification relies on the exceptional level of preservation, which in turn allowed a wealth of data to be generated and analysed. The unit-based approach adopted at this site may not be feasible for the majority of archaeological sites where soft hammer percussive behaviours may be present. Indeed, experimental replications suggest that soft hammer percussion lithic scatters produces a majority of flakes smaller than 20mm in maximum dimensions, and will be particularly vulnerable to post-depositional disruption as a result. Where conditions of preservation are not favourable, therefore, the archaeologist may be limited to the study of individual flakes; a process which, as noted above, retains a degree of unreliability.

Factors of preservation may therefore impinge on any attempt to establish the widespread use of soft hammer percussion from the archaeological record.

A second factor that may bring the recurrence of the soft hammer percussion technique into question concerns the fact that some complex methods detectable later in the archaeological record can be employed in its absence. The Levallois method, for example, represents a complex, multi-phase method that does not require the use of the soft hammer percussion technique (Boëda, 1995). The degree to which soft hammer percussion can viewed as integral to complex stone tool producing behaviours can therefore be questioned. Indeed, Hayden, who adopts the view that the soft hammer percussion technique is primarily employed to re-sharpen tools, contends that it is a technique that becomes eclipsed by more refined re-sharpening techniques over time (such as pressure flaking and edge-grinding) (Hayden, 1989). In contradiction to Hayden, however, it is worth noting that the soft hammer percussion technique does become incorporated in some later complex technologies. For example, the soft hammer percussion technique has been implicated in certain stages in the production of 'elongated flakes' associated with blade technologies (Soriano, et al., 2007: 682; Toth & Schick, 2007: 1959)[18], as well as prismatic blades (Sollberger & Patterson, 1976: 521). To assume a steady decline in soft hammer use is perhaps a one-dimensional interpretation. A more likely scenario would espouse varied degrees of cultural retention of the technique in some, but certainly not all, hominin groups over time. Overall, however, the soft hammer percussion technique is not integral to stone tool producing behaviours in the same way that hard hammer percussion appears to be, and its recurrence cannot be establish as robustly as a result.

4.7.2. Recurrence of the Task Domain of Soft Hammer Percussion

When considering the extent to which the soft hammer percussion technique recurs one needs to consider those factors that might introduce variability into the task domain. In the case of soft hammer percussion, one needs to consider whether such variability might stem from raw material properties or percussor type.

As with hard hammer percussion, the soft hammer percussion technique is inherently invariable due to the fact that its use is inextricably tied to the fracture properties of the raw material employed. In particular, it exploits a particular fracture property of the raw material: a property Cotterell and Kamminga refer to as the 'bending-initiated fracture' (1987: 683). This type of fracture relies of the effect that the soft percussor has when impacting on the raw material. Unlike instances of hard-hammer percussion, a soft hammer of wood, antler, or bone, compresses when it strikes a platform, causing the force of the blow to spread out (Newcomer, 1971: 89); as a result it is 'transmitted more slowly and evenly' through the raw material (Whittaker, 1994: 185). Again, there are constraints, stemming from the properties of the raw material itself, which determine whether a given soft hammer blow will succeed or fail. Learning to knap in accordance with these constraints would have represented a reliably recurring set of problems over time.

This assertion is further bolstered when one considers the issue of raw material selectivity, which is a behaviour that becomes more pervasive over time, up to and including the emergence of anatomically modern humans (Schick & Toth, 1993: 127). Raw material selectivity is particularly relevant to the use of the soft hammer percussion technique because, as Hayden notes, only a narrow range of lithic raw material types are suitable for its application (1989: 8-9, 12). Indeed, this selectivity would have been heightened by other factors, such as the transport of raw materials around the palaeolandscape (Hayden, 1989: 8). Given the energetic costs of transport, pressures would have existed over time for the selection of raw material types that display fracture properties that make soft hammer removals more amenable, which in turn would minimise any variability in the task domain stemming from raw material properties. Finally, the desirability of predictable fracture properties in raw materials is also alluded to by other archaeologically detectable behavioural strategies, such as the heat treatment of stone. Several studies have focused on evidence of raw materials being heated to high temperatures in order to modify fracture mechanics to make them more amenable to subsequent flaking (Brown, et al., 2009; Cotterell & Kamminga, 1987: 678; Domanski & Webb, 1992).

The use of either a soft stone hammer or organic billet is a further area where variability could be introduced in the task domain of soft hammer percussion. Where the use of a billet is employed, for example, the knapper needs to tailor blows to accommodate for the extension to the arm, while for a soft stone hammer the knapper holds the stone in a similar way to when using the hard hammer percussion technique. However, it is questionable whether this represents a problem type that differs significantly in cognitive terms. The nature of the flake removals means that some of the of the problems of the task domain are reliably encountered regardless of the percussor type, most notably in the requirement for blows to fall in marginal areas (Bradley & Sampson, 1986). Indeed, even if one accepts that billet use and soft stone use require the solution of different problems in the application of a blow, it remains difficult to assess whether one or the other was employed exclusively in handaxe production. Boxgrove presents a rather exceptional example where both soft stone hammer and billet use are indicated by the archaeological data, and where a preference for billet use is suggested (Wenban-Smith, 1999).

4.8. Fitness consequences of the Soft Hammer Percussion Technique

As stated above, the second criterion that defines an adaptive problem is that the successful solving of that problem bestows fitness benefits (in terms of either survival or reproduction) over time. Establishing whether the successful use of the soft hammer percussion technique has attendant fitness consequences requires a consideration of the archaeological evidence from two perspectives. Firstly, one needs to examine the proposed fitness consequences in terms of the technological benefits (i.e., what advantages does the soft hammer percussion technique bestow in terms of distinctive technological outcomes?). Secondly, one needs to examine the subsistence behaviours that are facilitated as a result and consider the extent to which these benefits can be intrinsically tied to the use of the soft hammer percussion technique.

Flake maximisation is one fitness benefit proposed for soft hammer percussion that stems directly from the distinctive types of flake removals the technique engenders. For example, Hayden (1989), and Hayden and Villeneuve (2009: 1164, 1167) envisage a shift in the Acheulean from inefficient hard hammer (i.e., Oldowan) flake production to a more efficient use of soft hammer flake production, which can be used to remove many more flakes from the same volume of raw material. Soft hammer percussion is critical to this shift, since the removal of thin, flat flakes with small bulbs of percussion facilitates the process of flake maximisation (Hayden, 1989: 12). Figure 4.18, for example, contrasts flake removals via hard hammer percussion with those of soft hammer percussion, and illustrates how soft hammer percussion flakes can be removed in larger volumes while using up much less of the raw material volume.

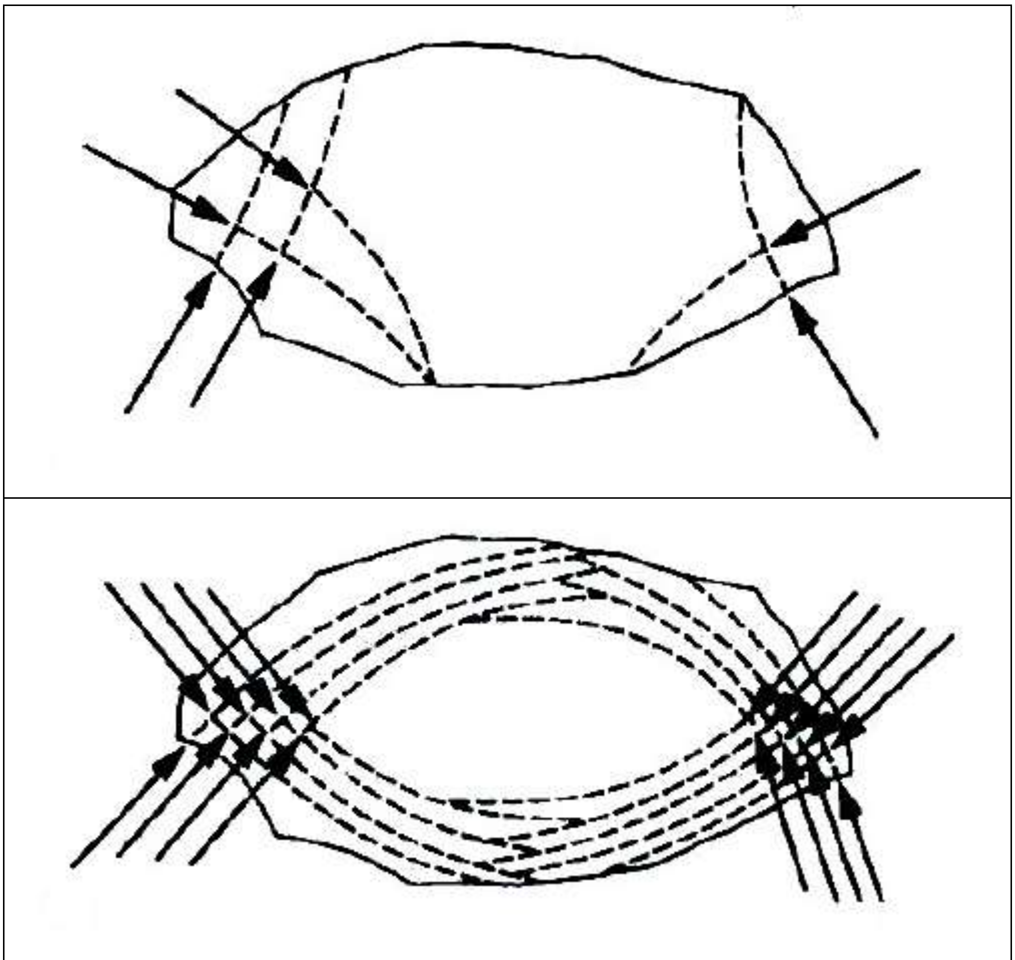

Figure 4.18: Diagrammatic representation of flake removal sequences via bifacial hard-hammer technique (top) and soft hammer percussion technique (bottom). Arrows represent the direction of the hammer strikes, and the dashed lines represent the fracture each strike engenders. Note the soft hammer technique allows the removal of a larger number of much thinner flakes from a given core volume (after Hayden & Villeneuve, 2009: 1164)

Indeed, Hayden and Villeneuve further propose that, in some contexts, soft hammer flakes were of primary adaptive importance, and that bifaces would have served as transportable sources of soft hammer flakes (Hayden & Villeneuve, 2009: 1167; Klein, 2009: 402), while the lack of innovation in re-sharpening technologies in the c.1 million years following the emergence of the soft hammer percussion technique is a testament to its efficacy (Hayden, 1989: 12).

Flake maximisation also carries distinct advantages in terms of subsistence, particularly in contexts where a dietary shift occurred over time to the consumption of larger volumes of meat. On this view, Oldowan-type technologies were inadequate for butchery on a large scale because flakes tend to blunt quickly in certain contexts (e.g., when cutting through dirty/muddy hair) and require frequent replacement (Hayden & Villeneuve, 2009: 1167). In such contexts, the hard hammer percussion technique of flake production would be ineffective in that it cannot be used to produce flakes in large numbers, and inefficient because it is a technique that is particularly wasteful of raw materials (Hayden & Villeneuve, 2009: 1167). For Hayden and Villeneuve, the soft hammer technique solves this problem by allowing many more flakes to be removed from a given mass of raw material and providing an efficient means of ad hoc flake production which would have represented a major improvement on Oldowan-type technologies (Hayden & Villeneuve, 2009: 1167).

The association of soft hammer percussion with butchery events is well evidenced from sites such as Boxgrove. Here, abundant archaeological evidence attests to a variety of butchery related activities such as skinning, dismemberment, filleting and marrow bone breakage (Parfitt & Roberts, 1999: 408), with cut marks representing the most common evidence of hominin alteration of bone (Parfitt & Roberts, 1999: 398). The faunal evidence suggests the processing of various species, including bear, rhinoceros, red deer, and, most abundantly of all, horse (Parfitt & Roberts, 1999: 402-410), with primary access being evident for the hominins through evidence of skinning/filleting and carnivore tooth marks overlying stone tool cut marks (Parfitt & Roberts, 1999: 414).

In addition to maximising the number of flakes that can be produced with the available raw material, a number of other corollaries regarding the adaptive benefits of the soft hammer percussion technique can be proposed from this model. Maximising raw material usage would reduce the need to revisit raw material sites, since it would increase the amount of work one could achieve from carrying a given mass of raw material (Hayden & Villeneuve, 2009: 1165). As Hayden notes, this would allow significant costs in terms of time and effort associated with the procurement of lithic resources to be avoided (Hayden, 1989: 9). A further consequence of maximising raw material usage would be to allow groups to range further afield from known raw material sources, because whatever lithic materials were transported within a group would have a longer use-life, and need replenishing less often (Hayden, 1989: 9; Hayden & Villeneuve, 2009: 1165). Here, then is at least one interpretation where the soft hammer percussion technique is, in itself, adaptively beneficial; solving the problems of the soft hammer percussion technique would allow the maximisation of flake production and had knock-on effects in terms of conferring behavioural flexibility.

A second area where the soft hammer percussion technique can be viewed as adaptively beneficial is linked to biface production. As will be discussed in the next chapter, both the archaeological evidence of prehistoric use, and experimental use in modern contexts, suggest that various fitness benefits can be attributed to the production of heavy chopping tools via the biface method. Though there are limits to how far one can exclusively link the soft hammer percussion technique with such benefits, particularly since bifacial tools can be made via hard hammer percussion alone (Whittaker, 1994: 178), the technique can be implicated in extending use-life of bifacial tools. Specifically, it can be used to rejuvenate the sharp cutting edge of a bifacial tool: '…billet-produced bifaces can be re-sharpened many more times than any core or core tool reduced by hard-hammer techniques' (Hayden & Villeneuve, 2009: 1167).

The benefits here are twofold. First, it is more expedient to engender a further series of soft-hammer removals to re-sharpen a biface than it is to make one from scratch every time the edge becomes blunt. Without this capacity one would need more frequent access to raw material sources, with the consequence that group mobility may be significantly reduced. Any strategy that extends the use life of bifacial tools in such a way would prove beneficial over time. Secondly, each re-sharpening episode has the additional benefits of producing highly useful soft-hammer flakes as a bi-product which, as argued above, can be usefully employed for various tasks.

4.9. Conclusion

In conclusion, this chapter began by arguing that stone tool production represents a diverse suite of potential adaptive problems that need to be demarcated prior any application of the methodology of Evolutionary Psychology. First, I proposed that stone tool production can be demarcated into the techniques and methods production, and further demarcated into specific examples of technique and method. For the purposes of this thesis, I proposed to apply the methodology of Evolutionary Psychology to hard and soft hammer percussion (for techniques) and the biface and Levallois (for methods)

The remainder of the chapter was devoted to examining the extent to which archaeological evidence can be used to demonstrate that hard and soft hammer percussion fulfil the criteria employed by evolutionary psychologists to identify an adaptive problem (i.e., recurrence and fitness consequences for survival or reproduction). It was argued that the issue of recurrence requires a dual consideration of both the occurrence of the respective techniques in the archaeological record and the possible incidence of variation in the task domain.

Regarding hard hammer percussion, robust archaeological evidence was discussed relating to its early use at various African sites dating between c. 2.6-2.2 million years, as well as later sites such as Olduvai Gorge (1.75 million years) and Dmanisi (1.7-1.8my). It was further argued that the hard hammer technique recurs in later contexts in the manufacturing process of more complex lithic technologies such as bifaces, Levallois tools, and blades.

The possibility of variation in the hard hammer task domain stemming from variability in raw material fracture properties was then considered. I argued that raw material variability only presented a challenge to the reliable recurrence of the problem types encountered in the hard hammer task domain in instances where lithic materials were selected at random. I further argued that behavioural strategies evident in the archaeological record relating to raw material selection would have introduced a bias for selecting materials with more predictable fracture properties.

Regarding fitness consequences, I argued that the archaeological evidence supports the view that the use of hard hammer percussion played a major role in opening a plethora of new subsistence niches, predominantly involving carcass butchery, but also various other cutting/scraping tasks. The adaptive advantage of utilising the hard hammer percussion technique was further inferred from both the energetic investment involved learning and using the technique, the effort involved in locating raw materials, and, as is evident at various Oldowan sites, the effort involved in the transport and retention of the raw materials. Lastly, I argued that one can infer subsistence benefits can be further inferred from the potentially maladaptive consequences of the niches that tool use opened up, most notably through the dangers of competition with other carnivores.

Regarding the soft hammer percussion technique, it was noted that the archaeological evidence from Boxgrove provides strong evidence for its utilisation as early as 524,000 – 420,000 years bp, and that the technique is also identifiable in Middle Palaeolithic and Middle Stone age industries in Europe, the Near East and Africa between 250,000 – 30, 000 years as well as in later Upper Palaeolithic contexts in the Near East, North Africa and Western Europe. However, I also argued that the recurrence of the soft hammer percussion technique cannot be established in the same robust terms as the hard hammer percussion technique due to the fact that some later complex methods can be applied using with hard hammer percussion alone (e.g., the Levallois method).

Regarding the recurrence of the soft hammer percussion technique task domain, I argued that the technique is inherently invariable due to the fact that its use is inextricably tied to the fracture properties of the raw material employed, which impose strict constraints on whether a soft hammer blow will succeed or fail. Learning to knap in accordance with these constraints would have represented a reliably recurring set of problems over time. In addition, I argued that raw material selectivity is even more crucial for soft hammer percussive tasks due to the fact that only a narrow range of lithic raw material types are suitable for its application. Such selectivity would serve to minimise any variability in the task domain stemming from properties of the raw material itself.

Concerning the fitness consequences associated with the use of the soft hammer percussion technique, I argued both technological benefits and subsistence benefits beyond those attainable via the use of hard hammer percussion needed consideration. The ability to maximise flake production from a core by using the soft hammer production technique presented a distinct technological benefit, effectively allowing many more flakes to be removed from a given volume of raw material. Other associated advantages stemming from flake maximisation were also indentified (such as the reduced need to visit raw material sites to replenish raw materials and the ability of groups to range further afield to meet subsistence needs). Finally, I argued that the soft hammer percussion technique represented a major improvement on hard hammer technologies by allowing more efficiency in butchery tasks, both in terms of allowing many more cutting flakes to be produced on site from a given core and in the production of heavy chopping tool.

Chapter 5: The Biface and Levallois Methods As Adaptive Problems

5.1. Introduction

The aim of this chapter is to examine the extent to which stone tool production methods fulfil the criteria employed by evolutionary psychologists to identify a viable adaptive target. To this end, I will examine two stone tool production methods: the biface method and the Levallois method. As in Chapter 4, the overall aim is to assess the extent to which stone tool production methods can be said to exhibit the two defining characteristics of an adaptive problem: i.e., there are attendant fitness consequences (for survival or reproduction) associated with the successful completion of the tasks, and the tasks are demonstrably recurrent over time in ancestral environments (Tooby & Cosmides, 2005: 21-22).

To establish whether there are fitness consequences associated with either the biface or Levallois methods I will examine the archaeological data relating to the two methods under consideration with an aim to explicating the various theories regarding how each was utilised in ancestral environments to produce favourable behavioural outcomes in terms of survival or reproduction.

Addressing the issue of recurrence for stone tool production methods, however, arguably requires a different approach to that adopted for stone tool production techniques. This is because the complete set of information-processing problems associated with a particular method recurs only as long as that method persists (i.e. while it is visible in the archaeological record). Though this does not negate the recurrence of the information-processing problems associated with method (as I argue below), it does necessitate a detailed consideration of how information-processing problems can be said to recur (or not recur) from method to method over time. As I will argue below, establishing recurrence for stone tool production methods involves identifying continuities between the biface and Levallois task domains (as opposed to establishing specificity as in earlier chapters discussing stone tool production techniques).

The rationale for focusing on these two methods particularly is threefold: firstly both the biface method and the Levallois method represent deep-seated and long lasting stone tool producing behaviours (as will be established below); secondly, the *chaîne opératoire* of both methods have been the subject of a good deal of previous research, which will prove a fruitful source of data for the task analysis of the respective task domains (Boëda, 1995; Chazan, 1997; Gowlett, 1984, 1996; Gowlett, 2009; Otte, 1995; Schlanger, 1996; Van Peer, 1995; Whittaker, 1994; Wynn, 1993a); thirdly, the two methods arguably document one of the most important conceptual shifts in the application of stone tool production methods (i.e., from façonnage to débitage) and should therefore prove a valuable source of comparison when considering the recurrence of information-processing problems between methods (Gamble, 1999; White & Pettitt, 1995).

Below, I will consider the two stone tool production methods in turn, first providing a brief definition of each method together with an overview of how the methods can be identified archaeologically, and an outline of the chronological and geographical occurrence of each method given the current state of archaeological knowledge. I will then consider the extent to which the two methods can be viewed as adaptive as per the two criteria. The various fitness consequences associated with each method will follow the sections containing the respective definitions and outlines of their archaeological occurrence. The issue of recurrence for the two methods will be addressed jointly in the final section.

5.2. The Biface Method: Definition, Identifiation and Occurrence

A biface is a stone tool that has had flakes removed from both faces (Whittaker, 1994: 178; Winton, 2005: 109). As Wynn notes, archaeologists tend to delineate bifacial tools into two types: handaxes and cleavers (2002: 394). The handaxe is perhaps the most recognisable form, with a characteristic teardrop shape (i.e., a pointed tip at the proximal end and a rounded butt at the distal end). Cleavers, meanwhile, have a 'transverse bit' instead of a pointed tip which is similar in appearance to a guillotine blade (See Figure 5.1). Bifacial tools are typically fashioned from 'large flakes struck from boulder cores or larger cobbles and nodules' (Toth & Schick, 2007: 1955).

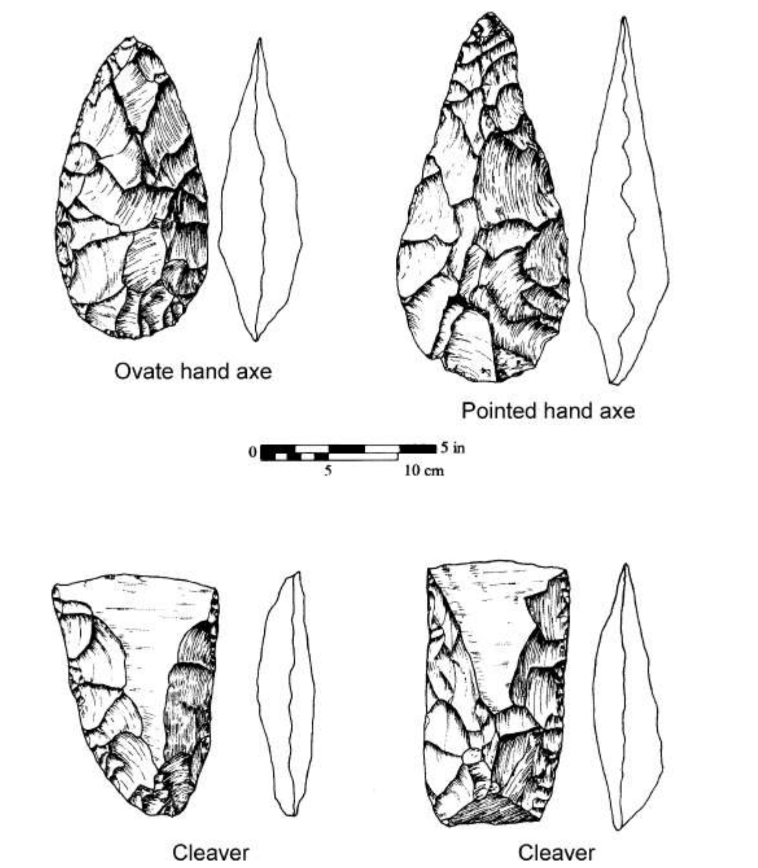

Figure 5.1: Two Types of Biface – Handaxes and Cleavers. Both handaxes (top) with their characteristic 'teardrop' shape, and Cleavers (bottom) with their large, transverse chopping edges, are bifacial tools (after Toth & Schick, 2007: 1956).

Given such a flake or cobble as a starting point, a standard interpretation of the application of the biface method would involve the removal of flakes from both sides of the core 'to produce a sharp edge around the entire periphery.' (Klein, 2009: 372). As conceived by modern knapping experts, this process comprises a series of distinct stages employing both the hard and soft hammer techniques (see Figure 5.2). Hard hammer percussion is employed initially to 'rough out' the raw material and to produce platforms amenable to soft-hammer percussion, which is subsequently used to remove characteristic 'thinning' flakes to thin the biface (Newcomer, 1971; Whittaker, 1994: 199-203).

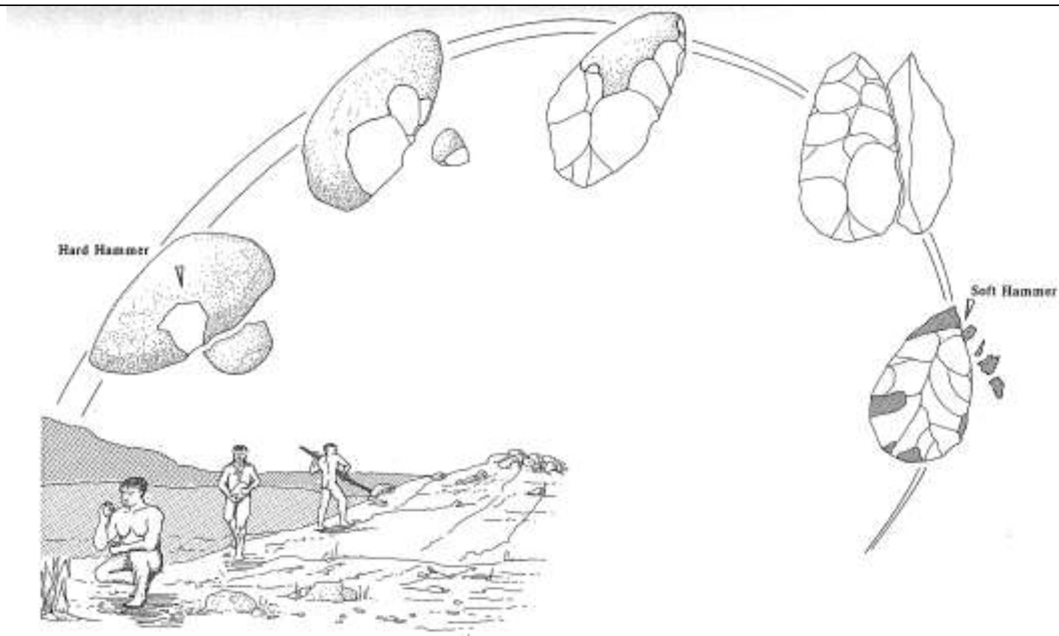

Figure 5.2: The Biface Method. Beginning with a large flake or cobble, successive flake removals are made around the periphery from both faces, producing a cutting surface around the entire edge (after Gamble, 1999: 131).

The biface method is often cited as a means to produce end products with similar morphologies, even when variation exists in the initial morphology of the raw materials (see Figure 5.3 for example). However, it should be noted that variations on the standard interpretation of the biface method are feasible (McBrearty & Tryon, 2006: 259), as has been recently argued from materials recovered from Isampur Quarry, India. Here, researchers argued that the specific biface method employed by prehistoric knappers depended on the initial morphology of the raw material, with thin slabs being used to produce handaxes and thicker slabs being used to produce cleavers (Shipton, Petraglia, & Paddayya, 2009b: 783, 784). Indeed, considerable variation exists in the biface *chaîne opératoire* concerning how workable blanks are obtained: Sharon, for example, proposes

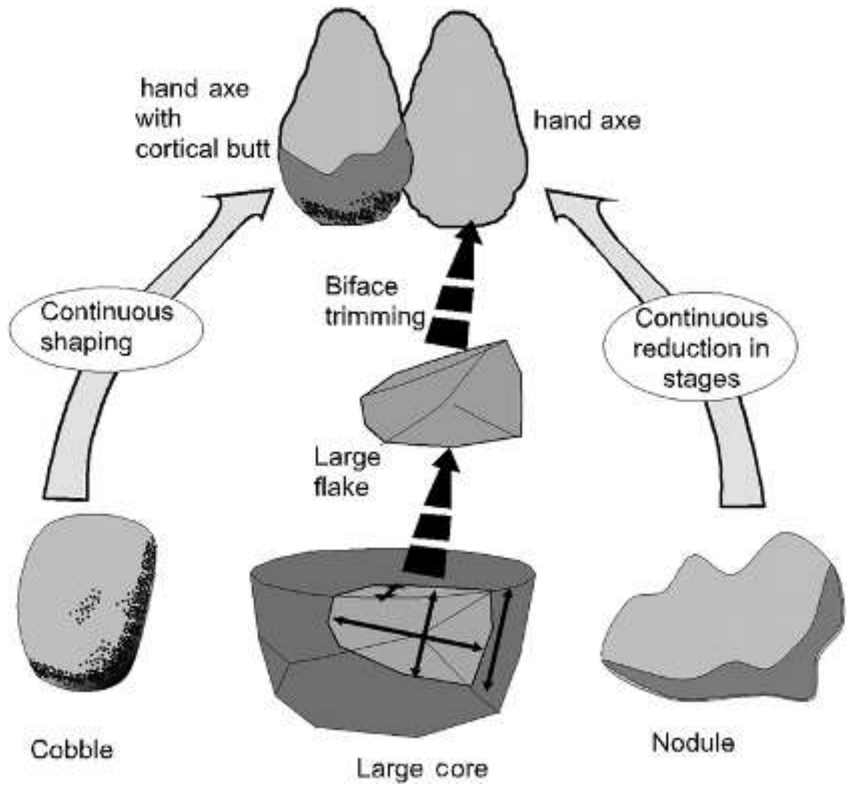

Figure 5.3: Three different strategies to produce a biface employing raw materials in various initial forms (after Gowlett, 2009: 406).

that there are as many as seven identifiable methods of producing flakes exceeding 10cm in length from a large core that can act as blanks for the biface method (2009b: 335)

For the purposes of this thesis, the biface method will be defined as a knapping method which aims to remove flakes from two faces of a core, incorporates several distinct stages, and employs both the hard hammer and soft hammer percussion techniques to achieve distinct aims with each stage. Though it is true that bifaces can be manufactured using the hard hammer technique alone (Whittaker, 1994), the focus here and in subsequent chapters will be on instantiations of the biface method that use both hard and soft hammer percussion. This is primarily because the incorporation of soft hammer percussion into the biface method arguably represents the most comprehensive account of the information-processing problems involved in its application.

5.2.1. Archaeological Identification

The use of the biface method in prehistory can typically be gleaned from the characteristic tool forms recovered in archaeological contexts. The analysis of surface flake scars indicate that successive removals have been engendered on both faces of the tool while the overall morphology may also display high levels of symmetry (Mithen, 2007: 298; Wynn, 2000: 122). The use of the biface method may also be inferred from lithic assemblages where the biface itself is absent, but soft-hammer percussion is evident (Whittaker, 1994: 180).

Where preservation allows, one can also glean the use of the biface method by comparing archaeological lithic remains with experimental debitage signatures:

> '…the investigator might replicate a biface from a flake blank or cobble. The debitage from that replication event is sorted into size grades and relative amounts of each size grade are calculated based on counts and weights and/or cortical representation. This control group is summarized to produce a signature of some type, such as a histogram, ratio measure, or a discriminant function. This control group signature is then compared to the signature obtained from the excavated collection using the same size grades. If the two signatures match, the investigator may infer that a biface was manufactured at that location, even if one was not found there.'(Andrefsky, 2009: 81)

Indeed, the detailed analysis of lithic materials can allow researchers to identify not only the presence of the biface method in general, but to identify the specific stages represented: the site of Boxgrove represents a good example of this kind of approach. At Unit 4c (Quarry 1, Area A) for example, the use of the biface method was identified based upon analysis of the lithic materials recovered (Austin, et al., 1999). Referring to experimental work conducted by Newcomer (1971) into the stages of handaxe manufacture, the authors identified roughing out, thinning, and finishing flakes, representing all stages of handaxe manufacture (Austin, et al., 1999: 317). However, based on the relative proportions of flakes, coupled with the fact that no flakes refitted to examples of recovered handaxes, they also concluded that no complete reduction process was represented, suggesting phases of manufacture occurring off-site (Austin, et al., 1999: 318).

In contrast, Unit 4b at Boxgrove yielded only thinning and finishing flakes (Austin, et al., 1999: 335). The early stages of manufacture are not represented in this scatter, as evidenced by an absence of hard hammer removals (Austin, et al., 1999: 339). Indeed, of the refits that were pieced together from Unit 4b, the two most extensive sequences (both > 20 flakes) were produced via soft hammer percussion alone (Austin, et al., 1999: 335).

With both these examples, therefore, researchers were able to state with confidence that the complete biface method was not represented, while also positing the specific stages represented based on flake morphologies.

5.2.2. Archaeological Occurrence

The earliest identifiable examples of the biface method date back to approximately 1.7 million years at sites in Peninj, Tanzania (Isaac & Curtis, 1974) and West Turkana, Kenya (Lepre, et al., 2011: 82). Bifaces become more common in the archaeological record after approximately 1.4 million years ago, occurring at notable African sites such as Konso-Gardula, Ethiopia (Asfaw, et al., 1992; Lewin & Foley, 2004: 345), Olduvai Gorge, Tanzania (Leakey, 1971; Schick & Toth, 2006), Olorgesailie, Kenya (Isaac & Isaac, 1977), and Wonderwerk, South Africa (Chazan, et al., 2008). Bifaces are also known from various sites along the north-eastern ‘corridor’ out of Africa, including Ubeidiya at c.1.4 million years, Evron Quarry at 1 million years and Gesher Benot Ya’aqov at 0.78 million years (Goren-Inbar, et al., 2000: 944).

European examples of bifacial technologies are typically later in date: for example, the British sites of Boxgrove (Roberts & Parfitt, 1999: xix) and Swanscombe (Bridgland, Gibbard, Harding, Kemp, & Southgate, 1985; Conway, McNabb, & Ashton, 1996) date to c.400,000 years and c.524,000-420,000 years respectively. However, excavations at the western Mediterranean sites of Solana del Zamborino and Estrecho del Quípar are challenging this view, where bifaces have been excavated from contexts purported to date to c.0.76 million years and c.0.9 million years respectively based on palaeomagnetic dating (Scott & Gibert, 2009: 82).

Following the point at which bifaces become more abundant at 1.4 million years they persists for over a millennia, becoming a dominant archaeological feature from 0.5 million years (Klein, 2009: 372; Mithen, 2007: 298). In terms of geographic range, bifacial tools are found in Africa, Europe and parts of Asia (McBrearty & Tryon, 2006: 258), with the 'Movius Line' designating the northward limits of the spread of bifacial technology into the rest of Asia (Bar-Yosef, 2006: 479). However, examples of bifacial technologies dating to c.0.8 million years have been recovered at some Asia locales beyond the Movius Line, such as at Bose, China (Yamei, et al., 2000). As Bar-Yosef emphasises, it is likely that there would have been punctuated episodes of biface method use by various groups over time; the method 'appeared and disappeared in different periods during the Pleistocene' (Bar-Yosef, 2006: 481). Ultimately, however, the archaeological record suggests that it was a technology widely adopted, prior to the a later technological shift to prepared core technologies (White & Pettitt, 1995).

5.3. Fitness Consequences Associated with the Bifacial Method

Schick and Toth note that bifaces have generated much controversy and speculation regarding their use/function (1993: 258) and various theories have been proposed regarding the possible associated fitness benefits. The most common theories (arguably the best supported in evidential terms) relate to increased fitness regarding the expansion and optimisation of subsistence opportunities. Bifaces are often viewed as general-purpose tools employed for a broad range of subsistence related tasks and activities, including butchery, cutting wood or bark, chopping vegetables, and various digging activities (e.g., for the extraction of roots, burrowing animals and water) (McBrearty & Tryon, 2006: 258;

Mithen, 2007: 298; Schick & Toth, 1993: 258-259). Indeed, in cases where microwear analysis has been feasible on bifaces, wear patterns appear to confirm they were used on 'materials ranging from meat and bone to wood and hide' (Lewin & Foley, 2004: 351). This in itself is not particularly revelatory, since microwear patterns on earlier Oldowan tools suggest they were used for a similarly broad range of tasks (Keeley, 1980).

However, one could still argue, *prima facie*, that bifacial tools must have conveyed adaptive benefits above and beyond those of the Oldowan based on the much greater investment of time and effort required for their production (Hayden & Villeneuve, 2009: 1167; Lewin & Foley, 2004: 345). This investment of effort includes not only the process of production (i.e., the physical and mental effort involved in removing a sequence of multiple flakes) but also the cultural retention of bifacial modes of production, where the complex process of a stone tool production method is learned within groups and passed down through generations. Such an investment would be otiose if simpler Oldowan tools could be used to complete the same tasks with equivalent ease.

Despite the complications of reconstructing subsistence activities from archaeological remains (and lithic technologies in particular), archaeologists have suggested a number of areas where bifacial technologies may indeed have promoted positive fitness consequences beyond those of earlier technologies.

The process of butchery or carcass processing represents one such area. Though both bifacial technologies and Oldowan tools were used for butchery tasks, experimental comparison supports the view that bifaces are quicker, safer and easier to use for such tasks. A study by Jones, for example, suggests that because a biface is larger and heavier than a flake, and with a longer cutting edge, a single stroke of a biface can complete a cutting task that would take ‘several more forceful strokes with a flake’ (1980: 159). The size and weight of a biface, as well as the ease with which is can be grasped, all contribute to making the work of butchery much easier, whereas the use of a flake necessitates ‘continuous tight gripping and forceful cutting’ (Jones, 1980: 159-160). To illustrate this point, Jones proposes a useful analogy between the efficiency of a carving knife (akin to a biface) compared to a small razor blade (akin to a flake) to carve a turkey (1980: 160).

As well as making butchery tasks easier to perform, there are at least two ways in which bifaces are safer to use than flakes. The first concerns the risk of accidental cuts to the hand of the user. Contrary to intuition, various butchery tasks can be completed with a biface that has been sharpened around the whole periphery with a low incidence of cut injuries to the hand holding the tool (Jones, 1980: 160)[19]. Flakes fare less favourably in comparison, with cut injuries occurring much more frequently (Ibid). This is significant, because for Pleistocene environments, even small, seemingly trivial cuts would have presented an unnecessary infection risk.

The second way in which the use of bifacial tools can be considered safer than Oldowan tools concerns the speed with which carcasses can be de-fleshed. In environments where pack predators and other carnivores presented a danger, the ability to quickly strip a carcass would have reduced the risk of confrontation (Hayden & Villeneuve, 2009: 1165). As argued previously, Oldowan tools also provide some advantage in this regard, but in comparative terms the positive fitness consequences of completing butchery tasks with alacrity would have been accentuated for hominin groups using bifacial, rather than flake-

[19] In his butchery experiments, Jones employed a biface similar in form to the ‘ovate’ handaxe in Figure 1.

type, technologies. Indeed, the durability of the cutting edge of bifacial tools, together with the ease of re-sharpening it, would also have contributed to the speed with which a carcass could be processed (Whittaker & McCall, 2001: 569). Flakes, by comparison, blunt quickly during butchery tasks, and since they cannot be re-sharpened in the same way as a bifacial tool, they need to be frequently replaced (Hayden & Villeneuve, 2009).

The symmetrical shape of some biface forms has also been cited as a source of functional efficiency for butchery (Bridgeman, 2002; Nowell & Chang, 2009; Simao, 2002; Winton, 2005). Bridgeman, for example, claims that symmetry, though not essential for all tools, can be very beneficial for specific task types (most notably, chopping) (2002: 403). Having a biface with a symmetrical morphology, as opposed to an irregular one, can have connotations for the ease with which it can be gripped, which can affect efficiency, precision, and safety during the completion of a cutting/chopping task (Nowell & Chang, 2009: 83; Simao, 2002: 419; Winton, 2005: 110).

On this view, any symmetry evident in biface form is a result of prehistoric hominins attempting to optimise the functional morphology of their butchery tools. However, this interpretation has been challenged by the experimental completion of butchery tasks using handaxe-type tools. For example, Machin *et al* (Machin, Hosfield, & Mithen, 2005, 2007) have employed both experienced and inexperienced butchers to test the efficiency of various handaxe forms for completing equivalent butchery tasks. Their conclusions suggest that symmetry contributed nothing to the efficiency or inefficiency of the tools used[20], and that the tool users primary concern was the nature of the cutting edge of the tool (Machin, et al., 2005: 35, 2007: 892).

Another area where bifacial technologies appear to have promoted positive fitness consequences concerns the expansion of the niche of meat consumption. Though experimental use suggests that bifacial technologies would have made very good butchery tools in general, Schick and Toth argue that they would have been particularly suited to heavy duty butchery, thereby facilitating the processing of large game carcasses (1993: 167, 258). For example, they argue that handaxes would have been efficient tools for cutting through thick skins; in contrast, they compare their experimental use of flakes on elephant hide to cutting through a car tyre with a razor blade (1993: 167). The adoption of 'highly stylized, large cutting tools' such the bifacial handaxe was, for Schick and Toth, 'an adaptive response to the dietary shift among early hominin populations in some parts of the Old World toward more habitual and systematic butchery' (Schick & Toth, 1993: 260).

This view is supported to an extent by archaeological evidence of hunting paraphernalia from Acheulean contexts, which strongly suggests that hominin meat acquisition behaviours had expanded beyond the scavenging niche and into the realms of active large game hunting. At Schöningen, Germany, for example, 400,000 year old spears have been discovered that display proportions similar to those of modern javelins (i.e., the main weight/thickness of the spear is at the front, with a long tapering tail), indicating that they would have been used for projectile hunting (Thieme, 1997: 809). The recovery of abundant faunal remains from the same context lends support to the view that large game species were being targeted (including elephant, rhinoceros, red deer, and bear) (Thieme,

[20] The efficiency of the tools was established through a combination of the speed with which the butchery tasks were completed and the subjective feedback from the participants of how easy each tool was to use (Machin, et al., 2005: 24-26).

1997: 808). Evidence linking the use of bifacial tools with carcass processing is also evident from sites such as Boxgrove (524,000-420, 000 years bp) (Roberts & Parfitt, 1999: xix). Cut mark evidence gleaned from the bones of large mammals (i.e., bear, giant deer, red deer, bison and rhinoceros) suggest that bifacial tools were implicated in a range of butchery tasks, including skinning, dismemberment, filleting,and marrow bone breakage, and that primary access to the carcasses was secured by the hominin group (Parfitt & Roberts, 1999: 403-408).

Given that meat represents a high quality food source, the ability of hominins to access more abundant sources of meat would have bestowed clear adaptive advantages (Aiello & Wheeler, 1995; Shipman & Walker, 1989). Indeed, some have argued that a positive feedback mechanism would have spurred the development of bifacial technologies once the association with the expanded meat-consuming niche became established. Hayden and Villeneuve, for example, argue that Oldowan-type technologies were inadequate for processing larger volumes of meat because flakes blunt quickly and frequently need replacing. Further, they argue that using the biface method in conjunction with the hard hammer technique only goes some way to solving this problem; it still remains ineffective for producing flakes in large numbers and is particularly wasteful of raw materials (Hayden & Villeneuve, 2009: 1167).

For Hayden and Villeneuve, it is only when the soft hammer technique becomes incorporated into the biface method that the efficient production of many flakes from a given mass of raw material becomes feasible, thereby providing an efficient means of *ad* *hoc* flake production (2009: 1167) [21]. If correct, this model suggests that the fitness consequences associated with the biface method may have evolved over time, and that the incorporation of the soft hammer technique into the biface method may have introduced positive fitness consequences that were previously unattainable, such as optimising the amount of work that could be completed with the available raw material, and reducing the need to revisit raw material sites (or, indeed, search for new ones).

Alongside the areas discussed above, a number of more conjectural theories have been posited regarding the fitness consequences associated with the biface method. The two most notable, perhaps, are the concept of the biface as a throwing weapon and Kohn and Mithen's theory that bifacial tools (particularly handaxes) were used as indicators of fitness in the process of sexual selection. Regarding the former, it has been suggested that bifacial tools represent well designed and efficient projectiles for throwing at game due to their symmetrical design, which fulfils an aerodynamic function accentuating spin when airborne (Calvin, 1993: 244; O'Brien, 1981). Calvin suggests that hominins may have used bifaces in such a way to ambush herd of animals at waterholes (Calvin, 1993: 245).

Though difficult to conclusively disprove or confirm (Ambrose, 2001: 1750), the notion of a discus-biface is unconvincing for a number of reasons. Firstly, a majority of bifaces do not exhibit the aerodynamic symmetry cited; secondly, the sharpened peripheral edge presents an injury risk during the process of throwing (akin to hurling a discus)[22]; and lastly, it would arguably not be very efficient. For example, Whittaker and McCall

[21] Note, however, that Hayden and Villeneuve's model does not advocate a dichotomous position, where hominids either made bifaces as cutting tools or used them as a source of flakes. They acknowledge that bifaces were also employed as tools for performing various cutting functions (Hayden & Villeneuve, 2009: 1167).
[22] O'Brien's original experimental work into handaxe throwing employed a fibreglass replicas which lacked the sharp peripheral edge (1981: 76)

question whether one could realistically fell a large animal with a biface, arguing that any damage to the animal would be superficial (2001: 568). Indeed, the notion of the biface as a projectile appears superfluous when one considers artefacts such as the Schöningen spears. If such weapons were ubiquitous in prehistory, Acheulean hominins may have possessed modes of projectile weaponry that would have rendered the discus-handaxe a prohibitively costly tool to manufacture in comparative terms[23].

Kohn and Mithen present a second speculative theory regarding the fitness consequences of the biface method in arguing that bifaces were a product of sexual selection (1999: 519). On this view, the ability to produce an aesthetically striking symmetrical handaxe served as a means of flaunting a hominid's potential capacity 'to secure food, find shelter, escape from predation and compete successfully within the social group' (Kohn & Mithen, 1999: 521). Handaxe manufacture may therefore have served as a proxy indicator of fitness, or of 'good genes', to prospective mates (Mithen, 2007: 301), performing a role in prehistory equivalent to brazen indicators of wealth in modern society, such as an expensive wrist watch or a yacht.

To support the notion of the biface as a product of sexual selection they cite various aspects of the archaeological record that are otherwise perplexing. For example, Kohn and Mithen propose that their theory explains the pervasiveness of the handaxe in prehistory; it explains anomalous sites (such as Olorgesailie) where large numbers of handaxes are found, apparently unused; it explains instances where apparently superfluous work and

[23] Though spears such as those recovered at Schoningen would arguably have been more efficient projectiles than handaxes, it should be noted that Calvin suggests another way in which a handaxe may serve a projectile function. For example, he argues that a biface projectile may have provided a means to panic a herd at a waterhole, causing them to stampede and injure weaker or younger members of the herd which can be despatched with ease (2002). Again, however, one would need to question whether the same effect would not be gained by a simple, unworked cobble, or by a projectile made of wood which would not require the same amount of effort in production.

effort has been spent shaping a biface (such as with the 'giant' handaxe in Figure 5.4); and lastly, it explains the tendency of knappers to produce symmetrical end products (thereby exploiting a pre-existing disposition to favour symmetrical features in a mate) (1999: 518-524).

Figure 5.4: A 'giant' ficron handaxe recovered from Cuxton, England (scale in cm). This handaxe has a total length of 30.7cm and weighs 1418g (after Wenban-Smith, 2004: 14-15)

Kohn and Mithen's theory has produced a lot of debate, though notably some critics have misunderstood or misinterpreted Kohn and Mithen's original proposal. Some, for example, reject it as an attempt to usurp all other functional explanations of biface morphology and use (Hayden & Villeneuve, 2009; Machin, 2008), whereas Kohn and

Mithen themselves explicitly state that bifaces likely served multiple functions (Kohn & Mithen, 1999: 521, 524; Mithen, 2008: 768). Indeed, that a tendency to indulge in ostentatious display might be included among those functions is a point accepted by Kohn and Mithen's staunchest critics[24].

Other criticisms, however, provide a more convincing rebuttal by focusing on alternative readings of the archaeological evidence. Nowell and Chang, for example, note that sites with bifaces deposited *en masse* are exceptional, with the majority of Acheulean sites yielding artefacts in more modest volumes (2009: 83). Additionally, they argue that where *en masse* accumulations occur they may have resulted from depositions covering several generations (i.e., hundreds of years), or represent a context distorted by taphonomic processes (2009: 83). Indeed, even if one were willing to accept that *en masse* accumulations were deposited in a brief timeframe, alternative explanations to Kohn and Mithen's are conceivable. Hayden and Villeneuve, for example, suggest they may represent raw material/tool stock piles, compiled in places where transit routes strayed from good raw material sources (2009: 1168).

Others have question whether the apparent lack of use on bifacial tools supports the view that their production was not primarily for practical use. Whittaker and McCall, for instance, note that very few biface sites have been the subject of systematic use-wear analysis and that for many sites such analysis is not practicable due to the influences of post-depositional factors (2001: 569). Nowell and Chang make the same point, noting that the abrasive action of fine silt movement can eradicate signs of use-wear, which might lead

[24] Hayden and Villeneuve, for example, dismiss the sexy handaxe theory as 'silly' while later conceding, in the same article, that it is likely that some handaxes may have fulfilled the non-functional, display-oriented role that Kohn and Mithen propose (Hayden & Villeneuve, 2009: 1163, 1168).

to the incorrect conclusion that certain handaxes were never used, and were deposited in ‘pristine’ condition (2009: 83).

Finally, concerning symmetry, Nowell and Chang note that this is not a universal trait: ‘perfect symmetrical handaxes actually represent a small percentage of handaxes’ (2009: 83). Furthermore, in cases where symmetry is evident, it is conceivably that this feature relates as much to functional efficiency than to the display of fitness (Bridgeman, 2002; Nowell & Chang, 2009; Simao, 2002; Winton, 2005). Alternatively, symmetry may simply be a necessary bi-product of the application of the soft-hammer reduction technique (Hayden & Villeneuve, 2009: 1167). The overall symmetry of a biface may therefore be akin to the conical head of a sharpened pencil: it may be symmetrical, with a degree of aesthetic appeal, but it is nevertheless a bi-product other processes and constraints (Hayden & Villeneuve, 2009: 1167).

5.4. The Levallois Method: Definition, Identifiation and Occurrence

The Levallois method is commonly perceived as a process whereby the knapper deliberately prepares/shapes a core in order to produce an end product (typically a flake) which displays predetermined morphological features (Gamble, 1999: 214; Klein, 2009: 379; Mithen, 1996: 119; Otte, 1995: 117; White, Ashton, & Scott, 2011)[25]. As noted by White, Ashton and Scott, the Levallois method was identified early in the development of Palaeolithic archaeology and has subsequently been the source of various disputes regarding its definition (2011: 54). Despite this fact, a consensus of sorts has emerged

[25] Though many archaeologists mention predetermination of final flake form as a defining feature of Levallois technologies, others, such as Davidson, have challenged this notion, citing archaeological examples where final flake forms are included in debitage (rather than being removed), and where anticipatory flakes are either missing from otherwise complete debitage sequences or display significant use wear, emphasising their utility for practical tasks (2010a: 223).

centring on Boëda's 'volumetric conception', which sets out six technical criteria that guide the Levallois method (Boëda, 1995: 46-52; White, et al., 2011: 54). As with the biface method, the 'classic' Levallois method involves progressing through a number of distinct stages (see Figure 5.5), but is commonly cited as requiring 'greater technical skill

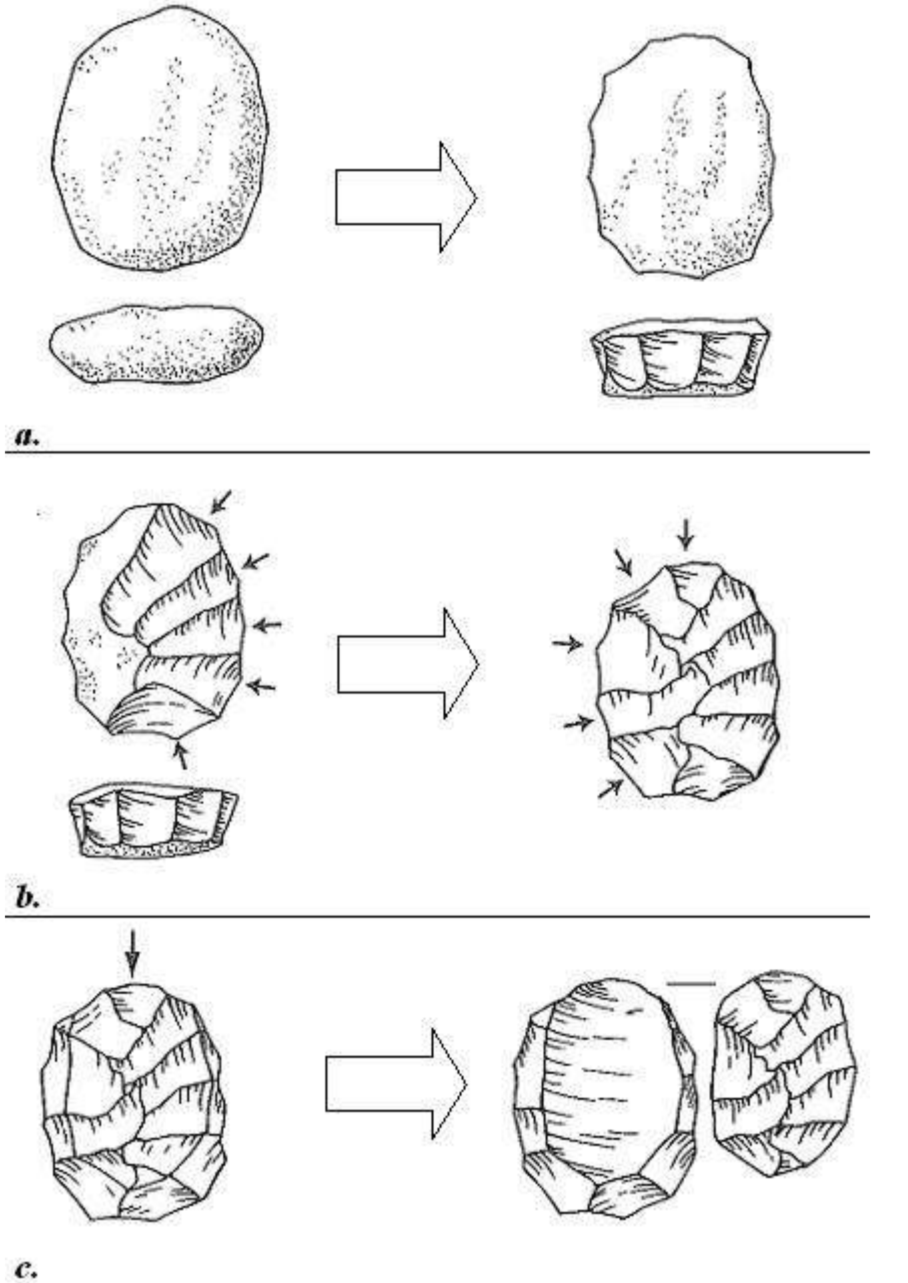

Figure 5.5: Reduction stages of the 'classic' Levallois method. Flakes are first removed from the periphery of an appropriately sized nodule of raw material (a); the flake scars of these initial removals are used to remove further flakes that are struck inwards, across the face of the core (b); a final hammer stone blow removes the final Levallois flake from the core (c) (after Klein, 2009: 487).

and forethought' than biface manufacture (Mithen, 2007: 310). In terms of technique, both the archaeological evidence and modern replication of the Levallois method supports the view that only hard hammer percussion was required (Chazan, 1997: 724; Klein, 2009: 486).

An ideal conception of the stages of the Levallois method can be summarised as follows. Given an adequately sized and shaped nodule with which to work, the knapper removes a series of flakes from around the entire periphery of the nodule (see Figure 5.5, section a). The flake scars from these peripheral removals provide subsequent striking platforms for the striking of further flakes that travel inward, across one surface of the core (see Figure 5.5, section b). Finally, when the inward radial flake removals have shaped the core surface satisfactorily, a blow is applied to remove a flake 'whose shape and size was determined by the arrangement of previous flake scars on the core surface' (see Figure 5.5, section c) (Klein, 2009: 487). At this stage, where the raw material volume allows, the core can be 're-shaped' by the knapper in order to produce a further exploitable surface for further flake removals (Boëda, 1995: 55; Pelegrin, 2005: 28) (see Figure 5.6).

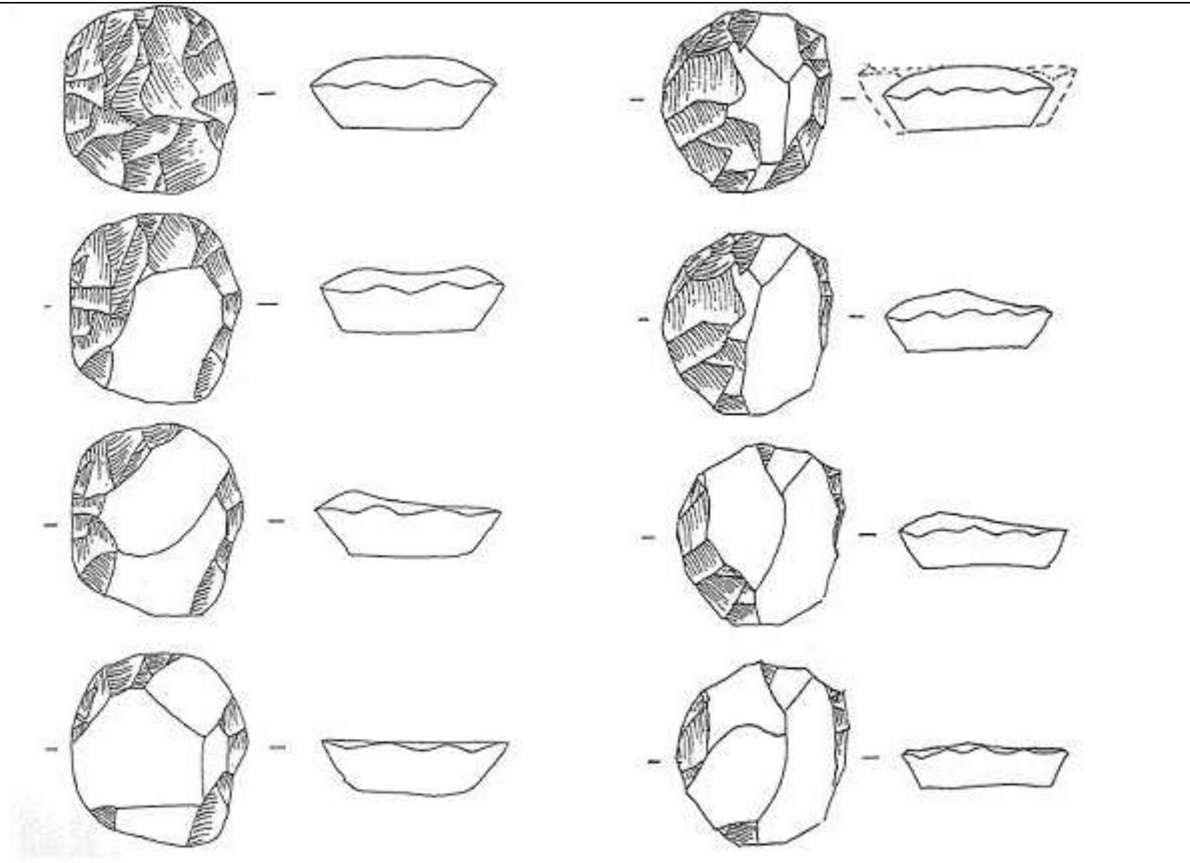

Figure 5.6: Example of core rejuvenation in the Levallois method. *Left (top to bottom)*: a series of Levallois flakes are removed from a prepared core. *Right (top):* the core is reshaped (the initial form is indicated by dashed lines). *Right (top to bottom):* Further Levallois flakes are removed from the exploitable surface of the core (after Boëda, 1995: 65).

Though often characterised as a method of producing a single predetermined flake as an end product, it should be noted that more than one 'final' flake can be produced in a given application of the Levallois method (Gamble, 1999: 214; Wynn & Coolidge, 2010: 90). As Boëda argues, based on the differing motivations of the knapper, the Levallois method can be split into two distinct method types, termed 'preferential' and 'récurrent' (1995: 56). The former involves the production of a single preferred end product (i.e., a blank/flake) for each core surface preparation; the latter involves the removal of several flakes for each core surface preparation (Boëda, 1995: 56) (see Figure 5.7).

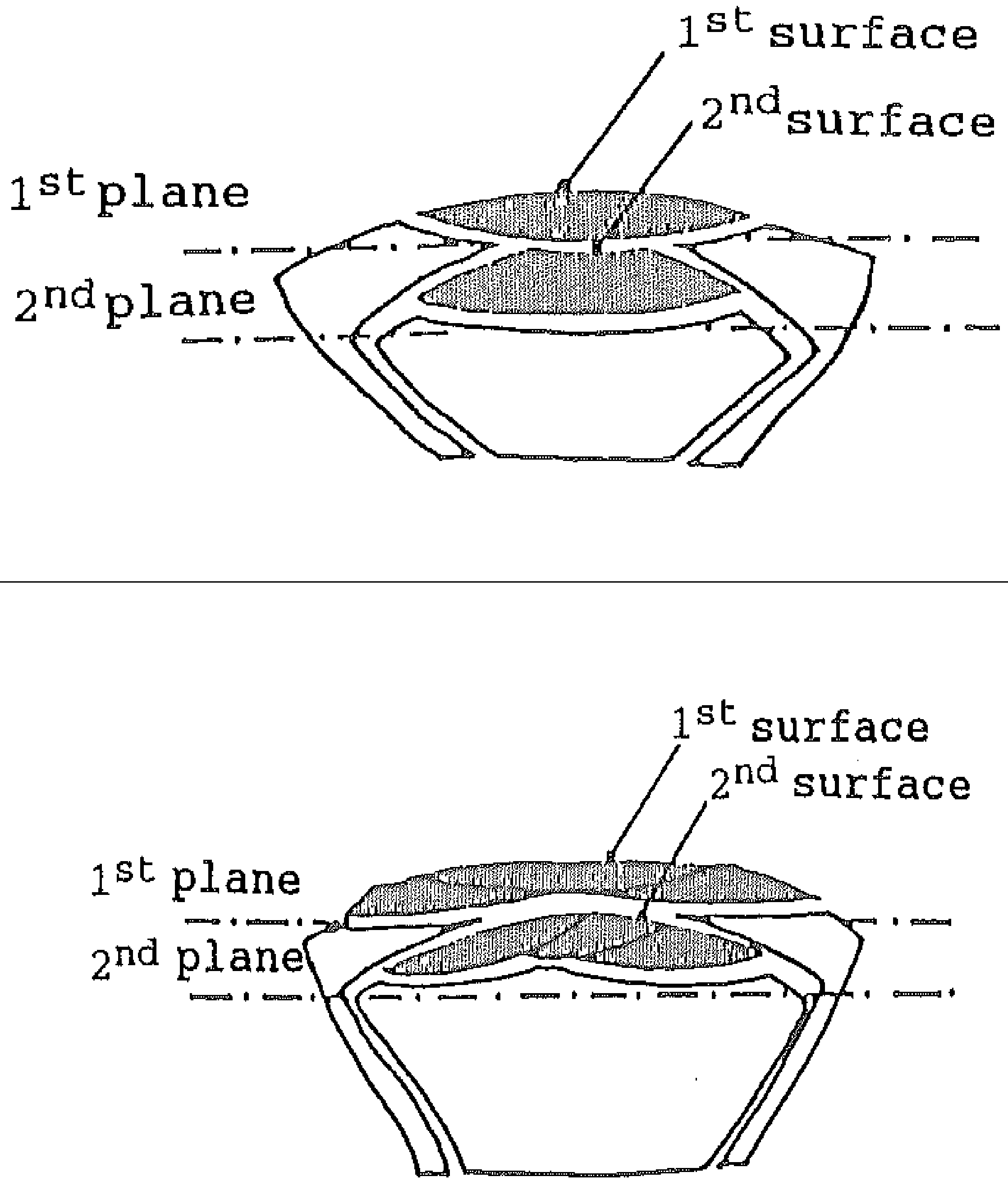

Figure 5.7: Preferential and récurrent Levallois debitage. Illustration showing ‘preferential’ Levallois debitage (top), where each preparation of the exploitable surface results in the removal of a single flake, in contrast to an illustration of ‘récurrent’ Levallois debitage (bottom), where each surface preparation yields multiple flakes (after Boëda, 1995: 56-57)

Additionally, it should be noted that there are many variations on the 'classic' Levallois method described above, both in terms of the end products produced and the reduction strategies adopted. In the case of the former, Levallois points and blades, for example, can be produced via the method in addition to flakes/blanks (Klein, 2009: 488; Schlanger, 1996: 237). In the case of the latter, there are various strategies that can be adopted by the knapper in the process of flake removal. For example, the knapper can strike flakes from the same end of the core (termed 'uniploar recurrent'), from opposite ends of the core on the same axis (termed 'bipolar recurrent'), or from various locations around the periphery (termed 'centripetal recurrent') (Schlanger, 1996: 239) (see Figure 5.8). Significant variation in morphology in terms of flake scars can result, as illustrated in Figure 5.9.

Moreover, the specific strategy adopted by the knapper has ramifications regarding the predetermined end product. Figure 5.10, for example, illustrates the connotations of adopting different core preparation strategies for flake morphologies. Despite the variation in terms of end product morphology and the specific knapping approach adopted, a common factor that is associated with all technologies produced with the Levallois method is that of predetermination of end product morphology (Van Peer, 1995: 6). For the purposes of this thesis, Boëda volumetric conception of the Levallois method, including all variations in its application that meet the six designated criteria, will be adopted and will be fully expounded in the task analysis (1995: 46-52).

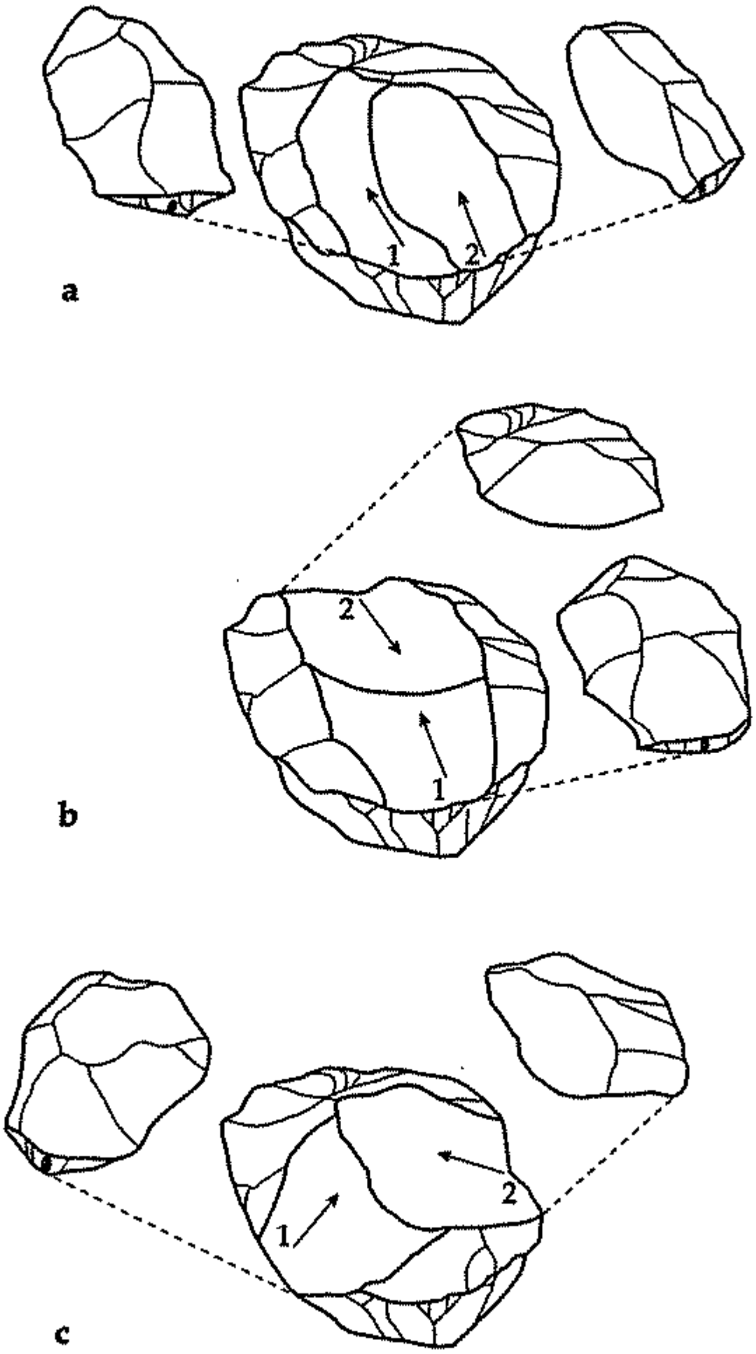

Figure 5.8: Three different approaches to the Levallois method. Uni-polar recurrent (a), where flakes are removed from one end of the core; bi-polar recurrent (b), where flakes are removed from alternate ends of the core on the same axis; centripetal recurrent (c), where flakes are removed from various locations on the periphery of the core (after Schlanger, 1996: 240).

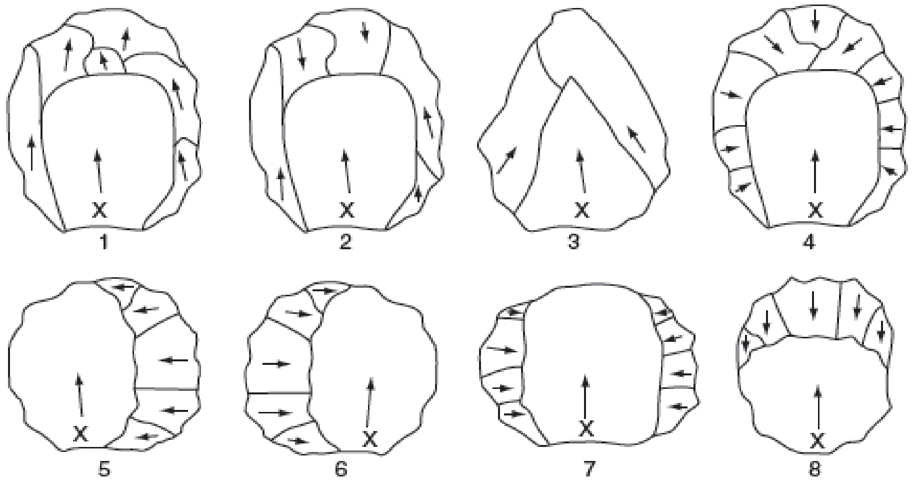

Figure 5.9: Illustration of various methods of surface preparation in the Levallois method as evidenced by surface flake scars: 1) Unipolar; 2. Bipolar; 3. Convergent unipolar; 4. Centripetal; 5. Unidirectional right; 6. Unidirectional left; 7. Bipolar lateral; 8. Unipolar distal (after Scott, 2006, cited in White, Ashton and Scott 2011: 55).

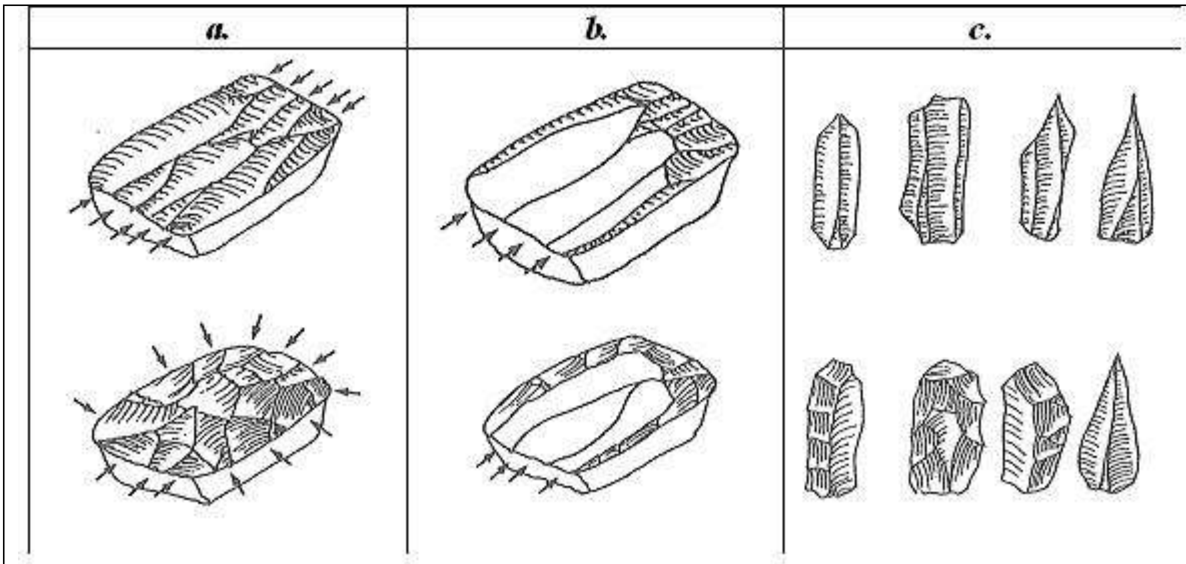

Figure 5.10: Illustration of the effect of different core preparation methods on the morphology of the end product in the Levallois method. Column *a.* shows two different cores prepared via two different methods of flake removal: bi-directional flake removals (top) and multi-directional flake removals (bottom). In column *b.* (top and bottom), four 'final' flakes are removed from each core via the same method (i.e., recurrent uni-directional), while column *c.* (top and bottom) illustrates the morphologies of these 'final' flakes. Note the residual flake scars on the surfaces of the end products. These morphological features are pre-determined by the initial shaping of the core (after Boëda, 1995: 62).

5.4.1. Archaeological Identification

The prehistoric application of the Levallois method can be inferred from the archaeological record in a number of ways. Perhaps the most secure way of identifying the Levallois method, where feasible, is through the refitting of lithic scatters. Schlanger's work on materials recovered at the Maastricht-Belvédère quarry in southern Limburg, Netherlands, for example, represents an extensive reconstruction of an example of Levallois reduction (1996). However, though reconstructions of a past operational schema can provide a reliable basis for identifying Levallois-type reduction strategies, examples of complete refits are not common due to the contingencies of sight formation and preservation.

Other methods of inferring the presence of the Levallois method from archaeological remains focuses on the diagnostic features on the flakes removed. For example, evidence of extensive platform modification can indicate the use of the Levallois method. Such modifications are used by the knapper to direct the force of the final blow to engender the desired fracture, and they are identifiable archaeologically in the form of '…flakes that have prepared or faceted striking platforms (or butts) as opposed to ones with unprepared or smooth platforms (or butts)' (Klein, 2009: 487). Figure 5.11, for example, illustrates an elaborate 'en chapeau de gendarme' platform preparation (Pelegrin, 2005: 29).

Other diagnostic flake features can also be drawn upon to identify the Levallois method. For example, Klein notes that Levallois flakes typically have 'dorsal scars reflecting deliberate preparation of the core surface' (2009: 487). However, identification and classification of the Levallois method from individual flakes is not always a straightforward process, as Boëda notes (1995: 41-45). One problem identified with the typological approach particularly concerns the fact that some products of an assemblage produced via Levallois operational schemas can be labelled ‘non-Levallois’; conversely, Levallois flakes can be mistakenly attributed to non-Levallois reduction methods (Copeland, 1981, cited in Boëda 1995: 41).

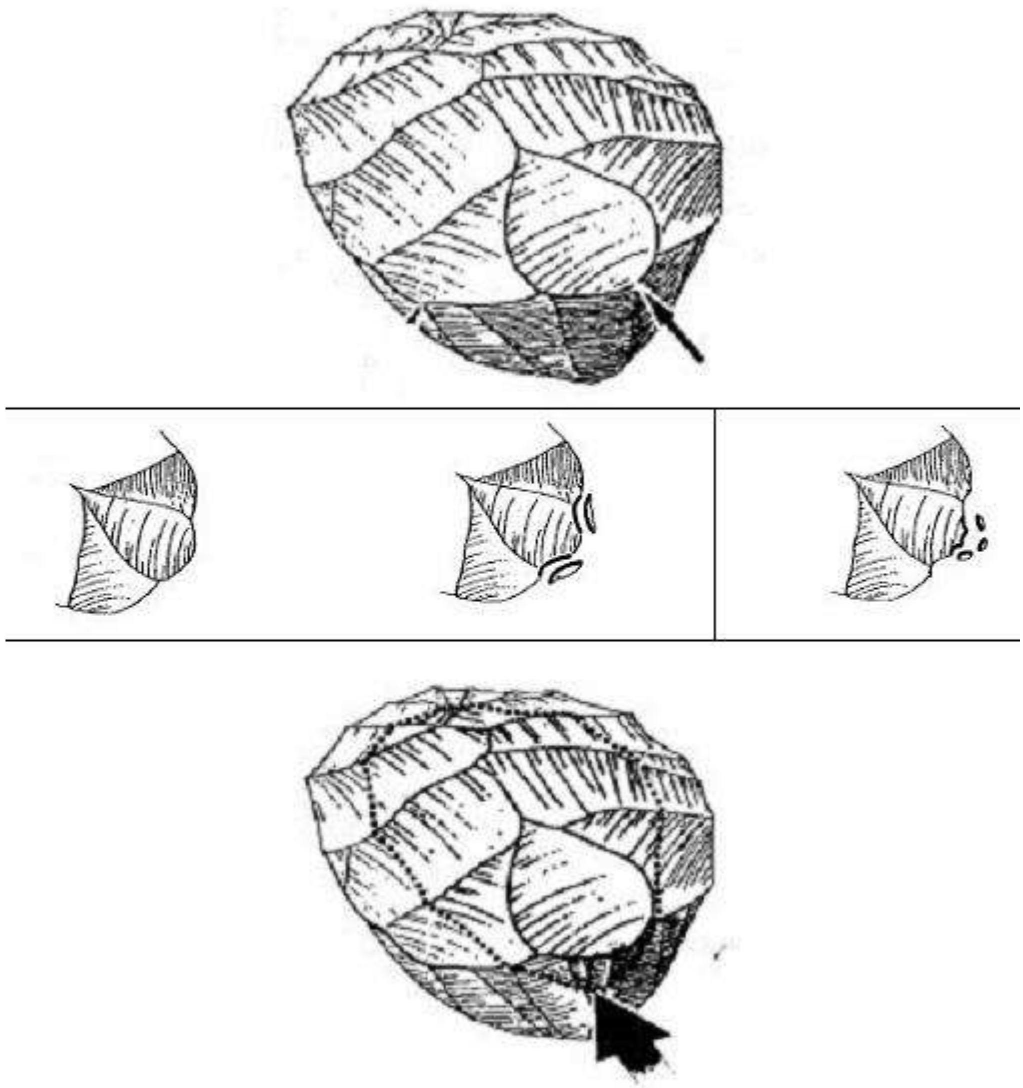

Figure 5.11: The Stages of ‘en chapeau de gendarme’ platform preparation. *Top:* the initial state of the pre-prepared core prior to any platform modification (the intended striking platform is indicated with an arrow). *Middle row (left to right):* plan view of the stages of the platform modification. Beginning the unprepared platform (left), the knapper first removes two flakes to produce an approximately triangular-shaped boss/hump (middle), before abrading or removing small ‘bladelet-flakes’ to give the boss/hump a facetted, rounded form (right). *Bottom:* the flake that will be removed from the finished core with its modified platform (adapted from Pelegrin, 2005: 29).

A pertinent example of the latter is provided by Van Peer, who notes that a ‘final flake’ refitted to a purported Levallois core identified at the Middle Palaeolithic site of Taramsa, Egypt, was shown, on reconstruction of the upper surface of the core, to be the result from a reduction strategy that differed from the Levallois method in a number of ways (Van Peer, 1995: 6). As Boëda emphasises, caution therefore needs to be exercised when positing the use of the Levallois method from individual pieces because operational schemas may be mistakenly attributed to a given assemblage (1995: 44).

Finally, the role of modern replication experiments should be noted, both in terms of replicating the end products of a particular method (Patterson, 1983) and in terms of establishing debitage signatures for the typical flake waste products that can be compared to archaeological remains to identify the prehistoric use of given method of reduction (Andrefsky, 2009: 81).

5.4.2. Archaeological Occurrence

The archaeological record suggests that the use of the Levallois method spanned various continents, including '…Africa, Western Eurasia up to Mongolia and southern Siberia inclusively, and the Indian subcontinent' (Rolland, 1995: 333) and was employed in a range of environments, including tropical, subtropical, temperate and periglacial climatic conditions (Toth & Schick, 2007: 1957). Examinations of the archaeological data to address the question of where the Levallois method originated has led some to propose that distinct processes of emergence can be traced for the African/Indian recorded verses the European record (Rolland, 1995: 333)

The African examples, often cited as the earliest prepared core technologies conforming to the criteria set out by Boëda, stem from chronological timeframes typical of the Acheulean

(White, et al., 2011: 58). For example, it has been argued that Mode 3-type technology is discernible in materials recovered from 1.5 million year old contexts at Nyabusosi, Uganda, (White, et al., 2011: 58). Similarly, de la Torre *et al* claim that the 1.6–1.4 million year old assemblage at Peninj, Tanzania, indicates planning and predetermination in the flaking process that follows a Levallois-type strategy of successive stages of core rejuvenation achieved by the reactivation of the convexities (de la Torre, Mora, Dominguez-Rodrigo, de Luque, & Alcala, 2003: 204, 222). Though the authors stress that the Peninj evidence is not strictly equivalent to later examples of the Levallois method, they do argue that 'the cognitive processes, the technical knowledge and the manual dexterity' employed by these knappers would have been largely the same (de la Torre, et al., 2003: 222).

Further African examples of prepared core technologies are evident in Eastern Africa from the Kapthurin Formation, Kenya, date to between c.284,000 and 509,000 years (McBrearty & Tryon, 2006: 262; Tryon, McBrearty, & Texier, 2006: 220). Similarly, various South African sites such as Canteen Koppie, Kathu Pan and Wonderwerk Cave have yielded evidence of the use of prepared core technology from c.1.1 million years to approximately 70,000 years (Beaumont & Vogel, 2006: 225). Levallois points are also evident from South African assemblages such as Wonderwerk Cave from c.500,000 years (Beaumont & Vogel, 2006: 221).

In contrast, the archaeological evidence suggests a later date for the emergence of the Levallois method in Europe (White, et al., 2011: 58). According to Tuffreau, the earliest occurrence of the Levallois in Europe can be traced to c.550,000 years (OIS 14) at Rue Marcellin Betholot, Saint-Acheul (Tuffreau, 1995: 417). The method can then be identified in various sites in Europe between c.550,000 years and c.330, 000 years (see White, et al., 2011: 58, and accompanying references for a concise summary) and becomes widespread across Europe by c. 244,000 years (MIS 7) (Tuffreau, 1995: 420; White & Pettitt, 1995: 33). This circumstance, paired with fact that 'all the currently documented variation' of Levallois was present by this time, leads White and Ashton to suggest that a 'rapid development, diversification, and dispersal' of the Levallois method occurred in Europe at this time (2003: 598).

Though there has been considerable debate regarding the origins of Levallois technology the focus of current research concerns the processes via which Levallois-type prepared core technologies emerged from bifacial technologies, which incorporate regional and temporal variability (McBrearty & Tryon, 2006: 261; Rolland, 1995; White & Ashton, 2003; White, et al., 2011). Rolland, for example, proposes a 'polyphyletic development' of the Levallois method based on his comparison of African and European examples, with 'varying raw material conditions' and 'pre-existing repertoires and motor habits' resulting in distinct modifications/innovations stemming from existing bifacial technologies (1995: 351). Similarly, White *et al* suggest multiple points of origin of the Levallois method stemming from various groups, rather than a single point of origin in time and space, but with a 'common technological root' in the form of bifacial technologies (2011: 62).

5.5. Fitness Consequences Associated with the Levallois Method

The use of the Levallois method has been linked to a number of outcomes that could have resulted in positive fitness consequences in prehistoric environments. These can be broadly delineated into the specific technological outcomes of the Levallois as a stone tool production method and the potential adaptive behaviours that the technological outcomes facilitate.

Regarding the technological outcomes of the Levallois method, Tryon *et al* summarise the main factors that would have contributed to the widespread adoption of the Levallois method as follows: ‘Levallois technology is likely to have been widely adopted because it provides the means to produce quantities of large, regularly shaped, relatively thin flakes, each bearing a substantial length of cutting edge’ (2006: 220). Economical exploitation of the raw material and the production of regular, standardised flake forms therefore represent two of the favourable outcomes of utilising the Levallois method. Lewin and Foley, for example, see an economical advantage in adopting the Levallois method because it produces ‘many more centimetres of working edge for each kilogram of core’ compared to the biface method (2004: 426).

Of equal importance, however, is that fact that utilising the Levallois method allows the knapper to exploit the raw material in an economical way while also producing flakes with a desired morphology (Brantingham & Kuhn, 2001, cited in Andrefsky 2009: 76). The trade-off here is minimal, meaning that the knapper does not need to make major sacrifices of economy to produce a flake of a desired morphology, or similarly sacrifice predictably of morphology to preserve raw material.

The knapper therefore enjoys the best of both worlds with the Levallois method, enjoying a degree of standardisation of end product while ensuring the efficient use of the raw material. This tendency towards standardisation is well illustrated by one of Schlanger’s observations from the study of Marjorie’s core, where the dimensions of Levallois flakes ‘do not decrease markedly towards the end of the sequence’ (1996: 243). Contrary to intuitive expectations, therefore, the progressive reduction of core size does not result in a corresponding reduction in size of flake products. The Levallois method therefore tends toward consistency in terms of size and shape of Levallois product regardless of the size of the core at any point in the reduction sequence (Schlanger, 1996: 243). Note also that the standardisation of flake products does not demand a restricted inventory of tool types. The Levallois method contributed to the production of a tool kit that included a diverse array of flake forms that each exhibit a degree of typological standardization (Klein, 2009: 488; Tuffreau, 1995: 424) and which, through further fashioning, can provide a wide variety of cutting, scraping, or piercing tools (Lewin & Foley, 2004: 426).

Perhaps the most important development in terms of fitness consequences that stems directly from the degree of standardisation in morphology that the Levallois method allows concerns the practice of hafting. As Ambrose notes, hafting behaviours are evident as early as the Acheulean to Middle Palaeolithic/MSA transition, as indicated by microwear traces of the mounts used, the identification of organic residues of mastic and morphological features on some tools (e.g., stemmed/tanged points) (2001: 1751). In terms of fitness benefits, hafting contributed to two broad areas relating to tool use: percussion and projectiles (Rots, Van Peer, & Vermeersch, 2011: 637).

Regarding the former, the use of the Levallois method contributed to the creation of percussion implements that were efficient for the purposes of ‘sub-surface exploitation of resources’ and woodworking (Rots, et al., 2011: 662:). Regarding the latter, the Levallois method is important for the production of Levallois points. As McBrearty and Tryon note, points can be used to fashion both spears and arrows, both examples of projectile technologies representing a general shift in the MSA from handheld artefacts to hafted technologies (2006: 259). The fitness consequences associated with such behaviours include an increased flexibility in hunting strategies as well as a reduced risk of injury[26]. The ability to inflict 'death at a distance' using arrows or spears reduces the risk of injury when hunting larger prey (McBrearty & Tryon, 2006: 259). The use of Levallois technology for creating projectile technologies is apparent from sites such as Umm el Tlel, Syria, where the fragment of a Levallois point was recovered from the cervical vertebrae of a wild ass; the location of the wound suggests a 'parabolic' trajectory, which supports the view that the weapon was thrown rather than thrusted (Boëda, et al., 1999: 394, 401).

Admittedly, this trend of hunting at a distance may not have been a universal tactic; evidence of trauma in Neanderthal specimens suggests that close-quarter hunting activities were also utilised, while simultaneously providing added credence to the view that the risk of injury is heightened when close-quarter strategies are adopted for large prey (Berger & Trinkaus, 1995; Schmitt & Churchill, 2003). Projectile technologies would also have been useful for hunting smaller animals that would otherwise be too nimble to catch.

In addition to the percussion and projectile functions of hafted tools, they also would have contributed much to the process of butchery. For example, from an examination of microwear patters for 157 tools from the French site of Biache-st-Vaast, dated to 253,000 years, Rots observes that a particularly large number of butchery-related tools can be identified (2013: 498, 505).

[26] Stiner, however, highlights a paradoxical feature of the Middle Palaeolithic archaeological record in noting that though abundant evidence for hunting exists, 'very few Middle Paleolithic tools can reasonably be called hunting weapons' (Stiner, 2002: 27)

Lastly, White and Pettitt argue that a corollary of the emergence of Levallois technology would have been an increase in mobility. On this view, Levallois reduction methods allow a more flexible response to the serendipitous demands encountered in the environment, thereby reducing the risks involved in ranging further afield (White & Pettitt, 1995: 34). However, they envisage a situation where increased mobility sparks the technological development, rather than vice versa:

> 'The broad Levallois concept encompasses many reduction strategies which can be varied both to meet the constraints of raw material, but more notably to meet demands as they arise [...] In short, a curated 'Levallois' core can fulfil a variety of tasks dictated by the dynamics of the environment. It follows that *mobility* in the environment will have greater effects on technology in this sense, far exceeding its effects on the static, situational reduction of raw material' (White & Pettitt, 1995: 34)

The fitness consequences associated with the adoption of the Levallois method in such instances would consist of a reduction of the various risks that accompany increased mobility; in contrast, the biface method represents a technology transported in finished form and which exhibits limitations in terms of its flexibility (White & Pettitt, 1995: 34). In behavioural terms, the kinds of fitness benefits that could be gained from an increase in mobility relate to practices such as hunting. The flexibility to successfully track and exploit herds of animals, for example, would be one possible advantage attainable by more mobile populations (a pattern supported by evidence of increasingly specialised hunting behaviours at this time) (White & Ashton, 2003: 606; White, et al., 2011: 57).

Indeed, certain aspects of the archaeological record support a view of increased mobility for Middle Palaeolithic/MSA populations. McBrearty and Tryon, for example, suggest that evidence of MSA sites occurring over time in areas that were previously unoccupied, and arguably hostile (e.g., in areas where water would have been scarce) suggests a ‘sophisticated strategy of landscape use’, arguably facilitated by the use of Levallois-type technologies (2006: 260). Furthermore, a direct correlation between increased mobility and the Levallois method has been proposed following research conducted by Geneste, for example, where increased transport distances of raw materials are associated with Levallois-type technologies (Geneste, 1985; Geneste, 1989, cited in White and Ashton 2003: 606).

5.6. Recurrence of the Biface and Levallois Methods

Establishing that the two methods under consideration are viable adaptive targets for the evolution of dedicated psychological mechanisms requires assessing whether the biface method and Levallois method present problems that reliably recur over time. As mentioned in previous chapters, the methodology of Evolutionary Psychology requires this step because the evolutionary process requires many generations to construct complex adaptations (Tooby & Cosmides, 1992: 69). In a similar sense to the previous examination of the recurrence of stone tool production techniques, establishing recurrence for the biface and Levallois methods requires a consideration of two main areas.

Firstly, it requires an examination of the archaeological occurrence of the methods under consideration in order to establish chronological depth and occurrence over time. Secondly, it requires an examination of the degree to which the respective task domain remains consistent over time in terms of the information-processing problems presented. Again, the focus is on two possible sources of variation in the information-processing problems involved. The first concerns possible variation as a result of factors relating to the environment/habitat (from a lack of uniformity in raw material properties, for example). The second concerns possible variation as a result of the cultural/behavioural factors (i.e., are there multiple possible realisations of the technique, which are utilised/retained to differing degrees in differing cultural contexts).

As outlined above, a strong case can be made that both the methods under consideration occur within chronological timeframes conducive to the evolution of dedicated cognitive mechanisms. The biface method, for example, is both chronologically deep-seated and long-lasting in the archaeological record (i.e., with origins extending back 1.7 million years and persisting for over 1 million years). Similarly, for the Levallois the cognitive processes involved in the method are arguably evident as early as 1.6-1.4 million years (de la Torre, et al., 2003), with more typical later examples of Levallois technologies dating back c.0.5 million years (McBrearty & Tryon, 2006: 262; Tryon, et al., 2006: 220; Tuffreau, 1995: 417) and persisting for approximately 300,000 years, becoming widespread in Europe by c. 244,000 years (Tuffreau, 1995: 420; White & Pettitt, 1995: 33) and persisting in some areas as late as 70,000 years (Beaumont & Vogel, 2006: 225).

Despite this, however, when considering the recurrence of the biface and Levallois methods one still is still confronted with the problem of the temporal limits of their occurrence over time. Previously, when considering the recurrence of stone tool production techniques, it was argued that the inherent links between the techniques and the fracture properties of the raw material ensured the robust recurrence of the information-processing problems over time. For the two methods under consideration, however, the task is not quite so straightforward.

One can see from the archaeological data that the biface and Levallois methods each have windows of chronological occurrence (however provisional). For each method the archaeological evidence provides an approximate 'first occurrence', an approximate end date, and a geographical spread (though with due caution given to possible distortions resulting from the vagaries of preservation). The extent to which each method can be said to recur over time therefore has immediate limits in existential terms. As Wells and Stock note, the cultural retention of a technology carries the inherent risk that the failure to pass on technical knowledge over time means the technology will necessarily die out:

> '[...] the capacity to make technology when required is as important as the technology itself. This benefit comes at the cost that such knowledge may be lost if both the articles, and those who know how to produce them, fail to be replaced over time.' (2007: 212)'

Clearly this fact has connotations for the extent to which one can argue that the information-processing problems presented by the biface method and Levallois method recur over time.

In response, however, one could argue that citing the chronological restrictions of each method as a barrier to recurrence is in fact wrongheaded. The crux of the issue concerns how one defines the adaptive target. If one defines the adaptive target of the biface method and the Levallois method in a rigid way then recurrence does indeed seem implausible. Pelegrin, for example, states that the method is a reduction process where a sequence of actions (the removal of successive flakes) results in a tool that shares morphological characteristics with other tools that are made employing the same method (Pelegrin, 2005: 24).

Now, for both the biface and Levallois methods, one can posit a complete *chaîne opératoire*, incorporating both physical and mental effort, which saliently captures every detail of the task domain. Performing the complete process associated with the biface method produces distinctive biface products, and likewise for the Levallois method. A rigid definition of a proposed adaptive target would identify the complete set of information-processing problems of either method as the only viable adaptive target. So conceived, these task domains do not recur beyond the populations in which they were created and utilised. Once the tool type disappears archaeologically, then the method (i.e. the systematised procedure that produces a Levallois flake) disappears also.

One can address this problem by noting that this rigid conception of the task domains overlooks the prospect of any shared information-processing problems between the methods by erroneously focusing on the distinctive aspects of the respective task domains. True, the two task domains will contain distinctive steps, but arguably these areas will not be the source of viable adaptive targets. Instead, one needs to focus on any information-processing problems which endure between the two task domains. Arguably, it is for problems of this type that recurrence can be demonstrated and where, over time, selection pressures would have caused the evolution of dedicated cognitive structures which would have solved method-related problems more efficiently than a 'general purpose' problem-solving capacity alone.

Indeed, on one reading the continuity of information-processing problems is hinted at in the archaeological data. For some, Mode 3 technologies, such as the Levallois, are technologies of 'convergence' and stem from various biface/Acheulean technological roots:

'…we can see a variety of roots converging on the same ultimate end, but regardless of whether emerging as a direct mutation of handaxes or an elaboration of existing core technologies, all are conceptually underwritten by the convergence into a single reflexive system of operational principles derived from two previously discrete operational schemes of 'débitage' and 'façonnage'. (White, et al., 2011: 61)

Indeed, this view suggests it would be a mistake to assume that with the emergence of each new stone tool production method a cognitive overhaul is required. Instead, the problems shared between the two domains may be more extensive than those problems that result in distinctive biface and Levallois products.

The main point of this line of argument can perhaps be summarised by stating that the human cognitive architecture will not contain psychological mechanisms specifically geared towards solving the information-processing problems of the biface method or the Levallois method. This places important limitations on notions like the 'mental template', which have previously been adopted by archaeologists. Gamble, for example, makes reference to the theory that stone tool shapes (as the product of stone tool production methods) stem from mental blueprints, or 'hard-wired cognitive structures' (Gamble 1999: 129). Arguably, important limitations can be placed on exactly which aspects of stone tool production methods can be 'hard-wired' when one considers the issue of the recurrence of information-processing problems. The focus is not on the minutiae that make each method distinct, but on the common information-processing problems underlying any instance where stone tool production methods are employed.

Indeed, the learning and use of language provides a useful analogy for comparative purposes in this case. The human cognitive architecture arguably contains structures that subtly guide the process of language acquisition (Chomsky, 1959; Pinker, 2002)[27]. However, the information-processing problems these structures solve do not correspond to any specific instantiation of language (i.e., there are no structures that promote the learning of Greek, Chinese, or Swahili, *per se*). Specific languages can therefore die out (i.e., fail to recur), while the information-processing problems relating to the use of language can endure. Seemingly, therefore, the structures within the human cognitive architecture relating to language acquisition evolved to solve information-processing problems that are common to all languages, such that they will reliably operate in any developmental environment where the relevant cues relating to language are present.

I would contend that any psychological mechanisms relating to stone tool production methods would have a similar form. The adaptive target for these mechanisms are the 'universals' that persist between the various instantiations of stone tool production methods, while the nuances of the task domains that make the biface and Levallois methods distinctive from each other are equivalent to those aspects of language that make Greek distinctively Greek, and Swahili distinctively Swahili. The expression of these distinctive aspects of a task domain contrasts with the universals in that the former are shaped and retained more by social context than by hard-wired cognitive structures[28].

[27] Chomsky , for example, captures this point succinctly in stating: 'The fact that all normal children acquire essentially comparable grammars of great complexity with remarkable rapidity suggests that human beings are somehow specially designed to do this, with data-handling or 'hypothesis-formulating' ability of unknown character and complexity' (1959: 52).

[28] Note, however, that social context may also be the source of the 'adaptive trigger' for stone tool production methods. Though it may be the case that psychological mechanisms exist to facilitate problem solving in the task domain, this ability will remain dormant without the requisite trigger from the environment: *viz.* the opportunity and motivation to engage in stone tool producing behaviours that involve the learning of a given method of reduction. This, too, is a factor that needs to be taken into account for the task analysis and any test design that results.

The above arguments also highlight an important corollary for how one approaches the task analysis for the task domains of the stone tool production methods under consideration. Namely, rather than examining the task domains of the biface and Levallois methods to identify what makes them distinct from one another[29], one will instead be trying to identify universal information-processing problems that recur between the task domains. Identifying those problems that can be considered recurrent, and, perhaps just as importantly, delineating them from those that cannot, therefore provides the first challenge in identifying those information-processing problems associated with stone tool production that the human cognitive architecture may have evolved structures to address.

The final area to consider regarding potential problems when considering the recurrence of the biface and Levallois methods concerns variability stemming from the respective task domains. This variability arguably has two potential sources. Firstly, it can stem from the fact that there are various instantiations identifiable archaeologically of the biface and Levallois methods (Boëda, 1995; Gowlett, 2009). The argument here would be that different instantiations of the biface or Levallois method may require the solution of differing information-processing problems, and variability is introduced into the task domains as a result. Secondly, and in a similar sense, variability could result from equifiniality, where a given end product can be produced via various means, and where different cognitive conclusions can be drawn in each case (Wynn, 2009: 147). Here, one could argue that variability may be present in the task domain of a given method even in cases where similar end products are being produced.

[29] Recall that this was the approach adopted for the task analysis of stone tool production techniques, where care was taken to establish the specificity of the posited information-processing problems to the task domains under consideration.

Both these arguments can be addressed if one considers the proposed adaptive target. As stated previously, the task analysis will seek to identify information-processing problems that are shared between the two methods. One could therefore suggest that if one identifies commonalities between the two methods under consideration, the same commonalities will maintain for different instantiations of each method. For example, if one posits that problem *X* is common to both the classic biface method and the Levallois *récurrent* centripetal method, one can likewise assume that problem *X* will also be solved in cleaver production and the Levallois *récurrent* unidirectional convergent method (Boëda, 1995: 60; Shipton, et al., 2009b). The fact that there is variation on the archetypal conception of the two methods under consideration therefore does not negate recurrence because the focus is on shared commonalities in terms of information-processing problems. To establish whether this is indeed the case the task analysis may therefore need to consider the biface and Levallois methods in various forms to assess whether the posited information-processing problems endure.

The same point maintains when considering equifiniality. For Wynn (2009), the fact that various reduction methods can produce similar end products becomes problematic in situations where different cognitive implications are involved. Specifically, one cannot attribute cognitive capacities beyond the ‘minimum competence’ required for the task under consideration (Wynn, 2009: 147). However, the fact that equifiniality restricts cognitive assessment to minimum competence is arguably not a problem in this case. As stated above, the focus here is on the identification of information-processing problems common to both the biface and Levallois methods (and, arguably, common to all equifinal instantiations of those methods). Establishing minimum competence in terms of the cognitive capacities required to use these methods in their various forms is exactly what the task analysis will seek to establish, because a psychological mechanism is most likely to have evolved to facilitate the acquisition of competencies of this kind. Even where more complex cognitive capabilities might be implicated in one method and not another, therefore, they will not be targeted in the test design.

5.7. Conclusion

In conclusion, in this chapter I have examined the extent to which the Levallois and biface methods fulfil the criteria employed by evolutionary psychologists to identify a viable adaptive target: i.e., that positive fitness consequences are associated with the use of each method, and that the information-processing problems associated with each method recur over time in ancestral environments.

I argued that the biface method would have bestowed positive fitness consequences in ancestral environments by allowing butchery tasks to be completed quicker and more safely when compared to earlier technologies. In addition, it was noted that the use of bifacial tools would have facilitated an expansion of the meat consuming niche by allowing the butchery of larger game. Speculative theories proposing that bifaces served as either projectile tools or fitness indicators for potential mates were also considered. The former was deemed impractical, while the latter relied on a skewed interpretation of the archaeological evidence. Overall, the link between bifacial technologies and the expansion of the meat consuming niche presents the most compelling evidence in terms of positive fitness consequences. Klein sums this sentiment up succinctly in stating that bifacial technologies '...probably had more in common with a Swiss army knife than with a peacock's tail' (Klein, 2009: 402).

In the case of the Levallois method, I argued that a combination of the economical exploitation of the raw material and the production of regular, standardised flakes (with a notable absence of a trade-off between the two outcomes) would have resulted in positive fitness consequences in two main areas. Firstly, the production of standard tool forms would have facilitated the creation of composite tools through hafting, which in turn allowed wider behavioural repertoires through the use of percussion and projectile tools. Secondly, the use of Levallois reduction methods would have promoted mobility in ancestral groups by allowing more varied responses to the serendipitous demands encountered in the environment.

Regarding recurrence, it was argued that the temporal limitations of each method negate the prospect of a psychological mechanism dedicated to the solution of the complete set of information-processing relating to either method. Establishing recurrence for stone tool production methods is therefore problematic if one takes the complete set of information-processing problems that comprise a given method as the adaptive target. Instead, one would anticipate that a psychological mechanism dedicated to dealing with the information-processing problems of stone tool production methods will be attuned to solving only those problems that persist from one method type to another. As a result, I argued that the task analysis for stone tool production methods will primarily be concerned with identifying the information-processing problems that recur between the two methods under consideration.

Chapter 6: A Task Analysis of the Hard and Soft Hammer Percussion Techniques

6.1. Introduction

The aim of this chapter is to perform a task analysis for the hard and soft hammer percussion techniques. As Tooby and Cosmides state, the aim of a task analysis is to specify the properties a programme would need to possess in order to provide a good solution to the adaptive problem under consideration (2005: 16). To this end, I will draw on evidence from expert knappers, together with data from experiments in fracture mechanics, to elucidate the information-processing problems associated with the task domains of hard and soft hammer percussion. For each technique the main variables that contribute to the success or failure of a flake removal will be highlighted. I argue that the appreciation, and co-ordinated control, of the blow angle, platform depth/blow precision, and blow strength capture the salient information-processing problems associated with both the hard and soft hammer percussion techniques, while also highlighting how these variables are attended to in different ways when the two techniques are compared.

Following this, I will consider whether the information-processing problems identified as salient to hard and soft hammer percussion techniques are specific to those tasks or whether, in fact, they are implicated in other manual tasks. For hard hammer percussion, an assessment of great ape manual skill will be conducted to examine whether those information-processing problems identified have a more general application in other task domains with a much deeper evolutionary history. For soft hammer percussion I consider whether the task domain for this technique is distinct enough in terms of the information-processing problems involved to require dedicated cognitive structures. In particular, I will assess whether the task domain of soft hammer percussion differs in significant ways from hard hammer percussion, particularly since the latter represents a percussive behaviour involving the fracture of lithic materials that has a much deeper chronological origin.

6.2. Expert Knappers and Experiments in Fracture Mechanics

A task analysis to precisely characterise the information-processing problems that need to be solved in the application of the hard and hammer percussion techniques can be informed, in the first instance, by consulting two sources of information. The first concerns the raw material. As a manual task, the successful use of both the hard and soft hammer percussion techniques relies upon, to a large extent, the manipulation of the fracture qualities of stone. In the case of hard hammer percussion, an ability to control conchoidal fracture is a fundamental aspect of the task (Nonaka, et al., 2010: 8), while for soft hammer percussion the ability to initiate bending fractures is required (Cotterell & Kamminga, 1987: 683).

Of particular use in this area are experimental studies into fracture mechanics that aim to quantify those variables that contribute to the removal of a flake from a core[30]. As Odell points out, '…understanding the ways rocks break constitutes the heart of lithic analysis, because this element is essential for comprehending processes of reduction – the quintessential lithic imperative – as it governs the form of both manufacture and use-wear.' (2000: 281-282). Similarly, from the perspective of Evolutionary Psychology, understanding how rocks fracture can elucidate various aspects of the task domain under

[30] Such experiments typically attempt to reproduce the actions of the knapper by dropping steel ball bearings onto plate glass cores from a certain height (Dibble & Pelcin, 1995; Speth, 1972; Whittaker, 1994), or mechanically replicate a soft hammer blow (Pelcin, 1997a). Recent experiments by Dibble and Rezek utilise a pneumatic hammer to deliver blows onto glass cores that have been moulded into a shape that reflects some typical core attributes (Dibble & Rezek, 2009).

consideration, and provide a basis for proposing what capacities a cognitive structure would require to solve them. As Tooby and Cosmides state: '...to map the structure of our cognitive devices, we need to understand the structures of the problems that they solve and the problem-relevant parts of the hunter-gatherer world.' (2006: 188-189). So if, for example, one wanted to study cognitive mechanisms relating to facial recognition, one would focus on the recurrent structures of faces (Tooby & Cosmides, 2006: 189) To study stone tool production, therefore, one needs to study the information-processing problems that are, quite literally, set in stone.

The second source of information for a task analysis of the hard and soft hammer percussion techniques comes from those individuals who are proficient in their use in modern contexts. Expert knappers can provide a means of examining both the physical actions that are required for knapping, as well as the thought processes behind those actions (Geribàs, et al., 2010), though with the obvious caveat that these thought processes need not necessarily be representative of those that were engaged in by prehistoric knappers.

Below, I will consult these two areas of information to perform a task analysis of the hard and soft hammer percussion techniques. The focus will primarily be on the information-processing problems encountered in the application of a single blow to remove a single flake. In adopting this approach, it is hoped, firstly, that the aspects of the tasks most closely linked to exploiting fracture properties will be explicated most fully, and secondly, that any temptation to erroneously incorporate any information-processing problems associated with sequences of removals (i.e., methods) will be avoided.

Clearly, the *chaîne opératoire* of the two techniques can be considered in a much broader sense (including, for example, stages such as sensing an initial need for the tool, selecting raw materials etc…) and in ways that extend beyond that of technique (i.e., for multiple blows on the same core, where removals can be seen to influence future removals in terms of changing the core morphology and the dynamics of the task). Where relevant, the aspects of the *chaîne opératoire* that are necessary prerequisites of the task domain of the two techniques will be briefly described prior to more detailed considerations of the those factors that contribute to single instances of flake removals via each technique. For clarity, when describing the measurable features of cores and flakes, I will adopt the terminology utilised by Whittaker (1994) throughout.

6.3. The Variables of the Hard Hammer Percussion Technique

Below I will focus on the three main variables that contribute to the removal of a flake via the hard hammer percussion technique. However, prior to any consideration of those variables, it is important to recognise certain prerequisites for the use of the technique that need to be satisfied prior to any acts of percussion. A complete *chaîne opératoire* for hard hammer percussion, for example, would include phases where raw materials are collected (i.e., core and hammerstone) (Haidle, 2009: 65) that are suitable for application of the technique (i.e., the raw material fractures conchoidally) (Whittaker, 1994: 65). Archaeological evidence suggests that this fact was appreciated by hominids using hard hammer percussion in the earliest identifiable contexts, who were selective about the raw material they chose to utilise, and also transport around the palaeolandscape (Braun, Plummer, Ditchfield, et al., 2009; Stout, et al., 2005; Toth & Schick, 2007: 1946). In addition to the physical qualities of the raw material, the morphological features of the raw material would also have been of importance (Nonaka, et al., 2010: 10). In particular, cores exhibiting favourable exterior platform angles would have been desirable (see Figure 6.1). One can therefore posit an assessment stage where a suitable striking platform is identified on the core.

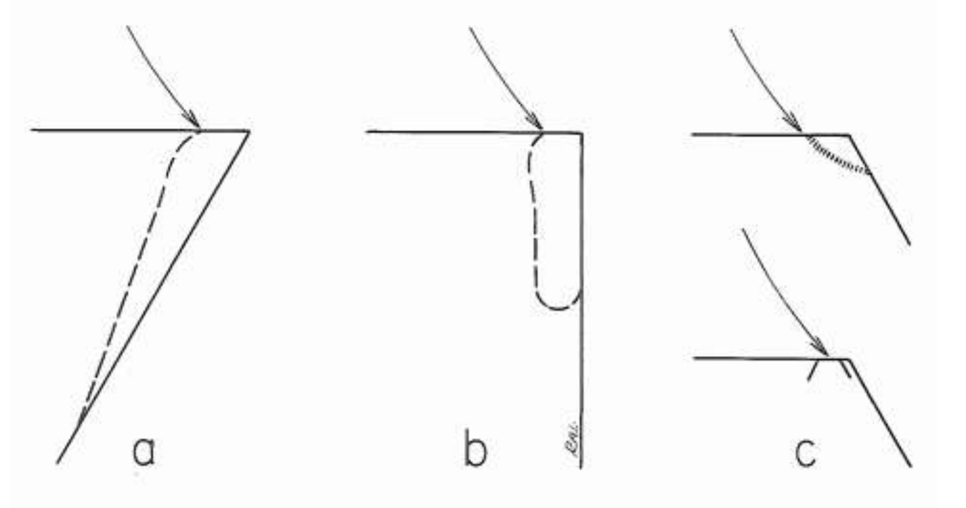

Figure 6.1: Exterior platform angle as a factor contributing to successful flake removal.

a) An exterior platform angle of less than 90° is conducive to flake removal, and retains a serviceable platform angle for further removals
b) An exterior platform angle of 90° produces a hinged flake, while further removals are complicated by the step left on the core
c) An exterior platform angle exceeding 90° results in the removal of an 'incipient cone' (top) or no removal at all (bottom) (Whittaker, 1994).

Assuming suitable raw material has been acquired and a suitable striking platform has been identified, there are three variables that can contribute to the outcome of a single flake removal via the hard hammer percussion technique. The knapper can actively alter or adjust one or more of these variables according to their specific aims, or in response to contingencies of raw material quality and/or morphology. When delivering a hammerstone blow, an individual utilising hard hammer percussion can affect the following:

- The blow angle (i.e., the angle made by the path of the blow and the platform – see Figure 6.2, *a*)

- The platform depth (i.e., how far from the edge of the platform the hammerstone strikes – see Figure 6.2, *b*)
- The strength of the hammerstone blow

Below, I will discuss how each of these variables affects the application of the hard hammer percussion technique.

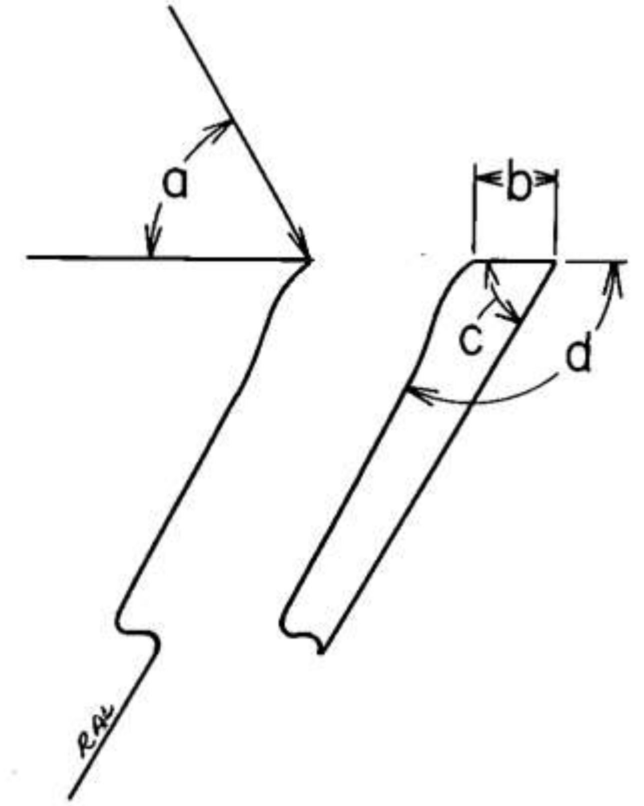

Figure 6.2: The measurable features on a core/flake during hard hammer percussion.

a) *Angle of blow:* the angle made between the striking platform (i.e., the surface of the core where the hammerstone strikes) and the trajectory of the hammerstone blow (represented by the straight arrow in angle 'a')
b) *Platform Depth:* the distance between the edge of the platform and the point of impact of the hammerstone blow
c) *Exterior platform angle:* angle between the outside edge of the flake and the platform
d) *Interior platform angle:* angle between the inside edge of the flake and the platform (after Whittaker, 1994)

6.3.1. The Blow Angle

The blow angle is defined as the angle formed between the striking platform on the core and the path of the hammerstone blow as it strikes the core (see Figure 6.2, *a*). Figure 6.3 shows three examples of flake removals where varying blow angles are applied (*a, b* and *c*).

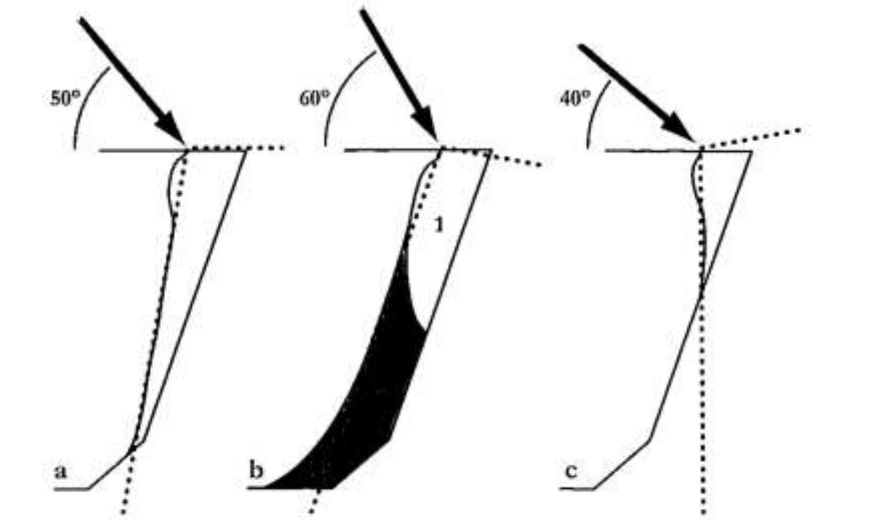

Figure 6.3: The effect of flake morphology on blow angle. The effect of varying blow angle on flake morphology (assuming uniform blow strength and platform depth) (after Pelegrin, 2005).

Comparing these different blows illustrates how blow angle can affect flake removal. In Figure 6.2, '*a*' can be viewed as the desired blow angle; a 50° blow angle in this case produces a flake of a decent length while maintaining the integrity of the striking platform (i.e., the exterior platform angle on the core remains less than 90° and is therefore conducive to the removal of subsequent flakes). In contrast, increasing the blow angle to 60°, as in '*b*', risks removing only a 'hinged' flake (labelled '1') which ruins the striking platform and complicates further flake removals. Lastly, a decreased blow angle of 40°, as in removal '*c*', results in only a small flake; much of the energy of the hammerstone blow will be wasted and the exterior platform angle left on the core sits at an unfavourable 90° angle.

Delivering a blow at the correct angle therefore has connotations for both the quality of the flake removed via a single hammerstone blow and the prospect of further flake removals from the same platform. Note, however, that the use of 50° as the optimal blow angle in Figure 6.3 is only for the sake of comparing the consequences of variations in the blow angle where all other factors are constant. In reality, there is no ideal blow angle that the knapper aims to achieve in every instance. As Whittaker points out, the only feature of the blow angle that will be consistent from one flake removal to another is that it will be less than 90° (1994). Beyond this, what counts as a good blow angle is contingent on the two other variables of platform depth and blow strength, as well as the morphological features of the core. Figure 6.4, for example, shows how different core morphologies (an inclining or declining striking platforms in this case) can necessiate adjustments in the blow angle.

In terms of analysing those information-processing problems that contribute to the task domain of hard hammer percussion, the ability to correctly judge the blow angle (as well as the ability to deliver such a blow) can therefore be viewed as information-processing problems that require solution. Getting the blow angle wrong in the application of hard hammer percussion can adversely affect a given knapping episode. Since the optimal angle for a blow varies due to a number of other factors (desired flake type, core morphology, variables such as platform depth and blow strength), deciding on the appropriate angle is a two step process. The first step will involve a mental assessment of the task in hand that takes into account the morphological features of the core, together with other variables, with the ultimate aim of decided on the optimal blow angle to achieve the desired flake; the second step is the actual delivery of the hammerstone strike at the desired angle.

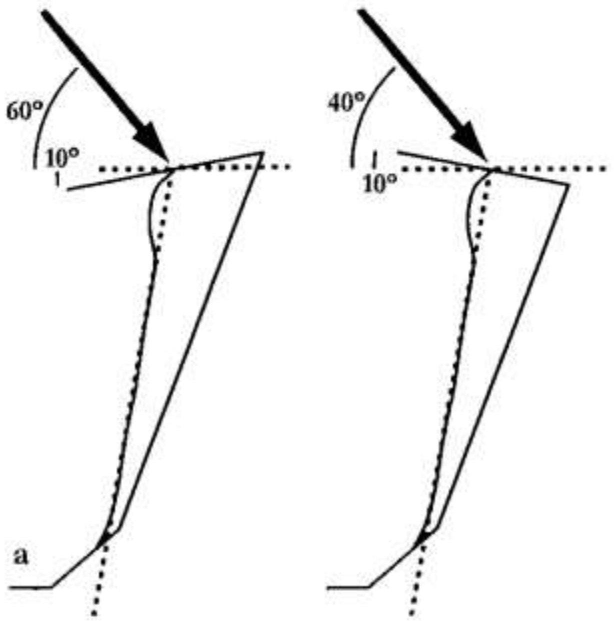

Figure 6.4: Adjusting blow angle to compensate variations in striking platform morphology. *Left:* for an inclining striking platform. *Right:* for a declining platform (after Pelegrin, 2005)

6.3.2. Platform Depth and Blow Precision

The platform depth is defined as the distance between the point of hammerstone strike and the edge of the striking platform (see angle *b*, Figure 6.2). Figure 6.5 illustrates how adjusting the platform depth can affect the morphology of the resulting flake. Again, let us consider '*a*' an ideal application of the hard hammer percussion technique, with a 50° blow angle producing a descent sized flake. Comparing the three scenarios illustrates how increasing or decreasing the platform depth (i.e., shifting the point of hammerstone impact toward or away from the edge of the striking platform), contributes to the thickness of the resulting flake. In '*b*', where the platform depth is increased, a thicker flake results; for ‘*c’*, in contrast, the impact location is closer to the edge of the platform, removing a much thinner flake.

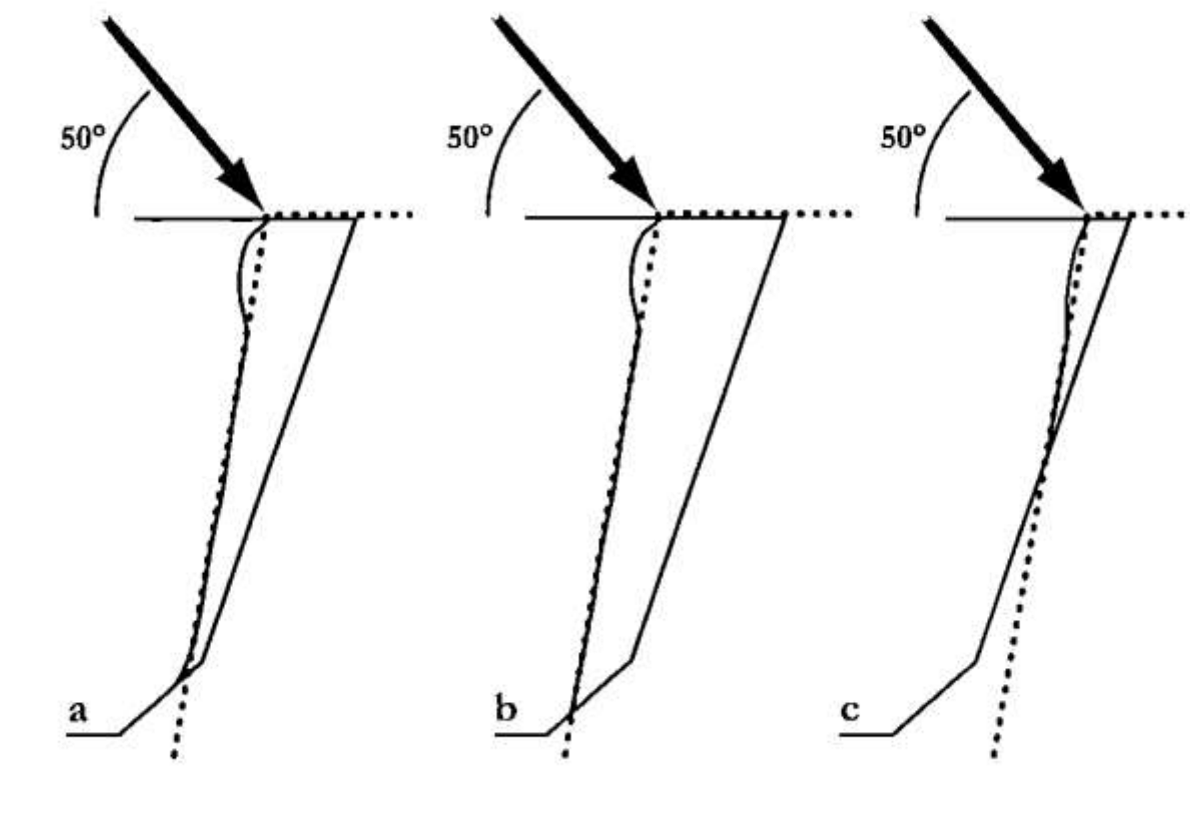

Figure 6.5: Platform depth and flake morphology. The effect of different platform depths on the morphology of the resulting flake (assuming uniform blow angle) (after Pelegrin, 2005).

There are certainly aspects of this variable that can be appreciated through common sense; platform depth is a measure between the point of impact and the edge of the striking platform, and therefore it is fairly obvious that moving the point of impact further back will produce a thicker flake, and moving it forward will produce a thinner one. However, as with blow angle, the contingencies of the core morphology can affect judgements relating to the platform depth. In Figure 6.6, for example, assessing the core for the ideal striking point (thereby dictating the platform depth) requires an ability to appreciate how an overhang or a slight curved indent might affect a removal, and adjust ones actions accordingly.

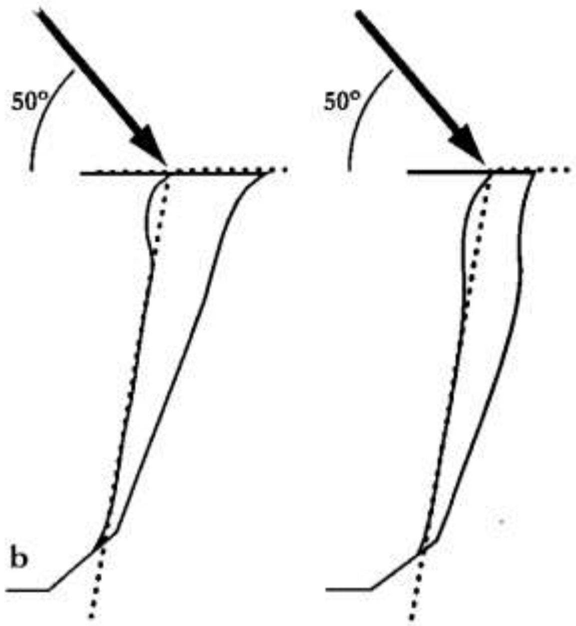

Figure 6.6: Platform depth and initial core morphology. Illustration of how different initial core morphologies can necessitate adjustments in platform depth (after Pelegrin, 2005).

As with the blow angle, therefore, the platform depth is important in terms of controlling the type of flake removed and, to a degree, ensuring the ongoing integrity of the platform[31]. Of particular importance for platform depth is the precision of the blow. Recent research demonstrates that the ability to accurately strike a core in a knapping episode varies significantly between novice, intermediate, and expert knappers. For example, experiments comparing predicted striking points on a core with the actual striking points achieved suggest that expert knappers deviate from their predicted striking point by a mean of only 0.6mm, while intermediates and novices deviate by means of 4.3mm and 7.4mm

[31] Whittaker notes that a platform can be crushed and ruined if struck at the wrong angle, or in the wrong place (1994: 99); failing to take into account core morphology when considering platform depth may therefore lead to failure in a knapping episode.

respectively (Nonaka, et al., 2010: 7). The successful control of the platform depth as a variable therefore requires an ability to deliver a precise blow at a predetermined point.

6.3.3. Blow Strength

The blow strength is the force with which the hammerstone strikes the platform. Contrary to popular perception, in utilising the hard hammer percussion technique a great deal of strength is not necessary to produce the kind of blow that will result in a successful flake removal (Dapena, et al., 2006: 337; Whittaker, 1994: 116). As with the platform depth and the blow angle, the blow strength needs to be carefully judged. However, there is some disagreement between expert knappers and researchers conducting empirical experiments into the variables involved in flake production as to the consequences of an error in blow strength judgement.

For expert knappers, blow strength is a variable of equal importance to blow angle and platform depth. Failure to judge the blow strength correctly can therefore affect both the quality of the resulting flake and the integrity of the striking platform in terms of further flake removals. Consider Figure 6.3 once more, and removal '*b*' in particular. As mentioned previously, a blow angle of 60° delivered at the same blow strength as removal '*a*' may result in an undesirable 'hinged' flake (labelled '1'). However, by increasing the blow strength in this case a longer, unhinged flake could conceivably be removed using the same 60° angle (the black segment in example '*b*' shows the kind of flake that would be detached) (Pelegrin, 2005). With the other variables held constant, blow strength can therefore make the difference between a favourable removal and a hinge/step termination. If the blow strength is below what is required to remove a flake cleanly, it will terminate prematurely and leave a 'step' on the core (a feature which interferes with subsequent flake removals) (Whittaker, 1994: 109).

Conversely, researchers conducting empirical experiments into fracture mechanics propose that blow strength is of secondary importance when compared to other variables, and that the force required to remove a flake is more accurately viewed as a 'threshold' which needs to be met. For Dibble and Pelcin, and also Dibble and Rezek, the important variables that dictate the morphology of a flake are the exterior platform angle and the platform depth (Dibble & Pelcin, 1995: 435; Dibble & Rezek, 2009: 1952). On this view, the blow strength is either sufficient to realise the removal of the flake, or it is not; striking a harder or softer blow cannot influence flake morphology, therefore, but only whether the flake will be removed at all (Nonaka, et al., 2010: 3). Referring to their own experiment in fracture mechanics, for example, Dibble and Rezek conclude that:

> 'Using less force […] results in a ring crack and no flake being produced; applying more force […] has no effect whatsoever, because once the force reaches the minimum point, the flake itself detaches and no more force is applied. Therefore, given particular values of exterior platform angle, platform depth and angle of blow, the resulting flake will have a particular mass, no matter how hard the core is struck.' (Dibble & Rezek, 2009: 1951)

So there is a conflict between, on the one hand, what can be established through examination of fracture mechanics in experimental settings, and on the other, what is known from firsthand experience of the task domain of hard hammer percussion. Though the experimental results appear to support a threshold interpretation for blow strength as a variable, the degree to which it can provide a model for 'real world' knapping may be compromised both by the raw materials used (i.e., moulded glass cores) and the method adopted to mimic the hard hammer percussion technique. Odell, for example, has questioned the extent to which such experiments relate to real world situations (2000: 283). Indeed, it is notable that on the threshold model hinge/step terminations should not occur at all, whereas such hazards are commonly cited by experts in the field of knapping (Pelegrin, 2005; Whittaker, 1994)[32]. Finally, experiments that compare the technical abilities of novice, intermediate, and expert knappers suggest that an ability to judge and deliver blows of a particular strength is a skill that is demonstrably more refined in experts (Nonaka, et al., 2010)[33].

For the present analysis of the task domain of hard hammer percussion blow strength will therefore be considered as a variable that can affect both flake quality and the integrity of the striking platform. As with blow angle and platform depth, it requires consideration firstly in the assessment stage where the core is examined and decisions are made regarding the type of blow required, and also in the second stage where the actual blow is delivered.

6.3.4. Co-ordination and Learning

Though an ability to judge a blow angle, an ability to deliver a precise blow at a predetermined point, and an ability to judge and adjust blow strength can all be considered information-processing problems salient to hard hammer percussion, a further information-processing problem associated with these variables is the high degree of co-ordination

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[32] Of course, the fact that hinge/step terminations are common in knapping does not prove that they are due to misjudgements in blow strength alone; other factors may contribute, such as aberrations in the raw material.
[33] For example, expert knappers apply blows with much lower kinetic energy, suggesting they have an appreciation of the precise blow strength that is required to remove a flake. Similarly, experts were more proficient in adjusting blow strength when it was necessary to remove flakes with differing dimensions.

required in accounting for them in a single, instantaneous strike. As Pelegrin points out, the ability to use hard hammer percussion to exploit conchoidal fracture requires precision that far exceeds techniques such as ‘bi-polar’ split breaking; it is a marker of ‘true bi-manual dexterity’ in the sense that the left and right hands are fulfilling distinct roles that need to be synchronised at the moment of impact (Pelegrin, 2005: 25)[34]. Once an assessment of the core has been carried out, the delivery of the hammerstone blow involves the simultaneous control of these three aspects (i.e., strength, angle, and precision) in real-time, and requires complex motor organisation (Stout & Chaminade, 2007: 1096).

There is, therefore, much scope for error in the application of the hard hammer percussion technique. Consider, for example, the initial stage of assessment of the core. Any decisions made at this stage regarding blow application (i.e., angle, strength, or point of impact) may result in failure even if the blow is delivered exactly as desired. Similarly, one may accurately identify the kind of blow required in the initial assessment stage, only for failure to occur due to errors in the application of the blow; since there are three potential source of error in the blow application, an ability to co-ordinate and attend to the variables simultaneously appears vital. For example, one may judge the blow strength perfectly, and yet suffer failure due to striking further back on the platform than anticipated (meaning the force is no longer adequate for the desired flake). Similarly, one could judge the platform depth and blow strength perfectly, but misjudge the blow angle. With all these factors contributing to the success or otherwise of the hard hammer percussion

[34] A study by Dapena et al which examined the biomechanics of arm swing for stone tool production found that the subjects tended to move the core (held in the non-dominant hand) up to meet the hammerstone blow; the researchers propose that blow strength can be increased in this way (2006: 336). Stout and Chaminade, similarly, note that the non-dominant hand has an important role in supporting, positioning, and orientating the core (2007).

technique, it is hardly surprising that attaining a level of expertise requires both practice and learning (Geribàs, et al., 2010; Stout & Chaminade, 2007).

6.4. The Variables of the Soft Hammer Percussion Technique

As with the discussion of hard hammer percussion above, there are certain prerequisites that need to be met for the successful application of the soft hammer percussion technique. Again, suitable raw material with predictable fracture properties needs to be located, together with a suitable soft hammer of stone, bone, wood or antler. Perhaps more significantly, however, the soft hammer percussion technique requires prior preparation of a core by the knapper to create platforms conducive to soft hammer removals. Though it is feasible to employ naturally occurring platforms on the raw material, archaeologists generally cite active creation of soft-hammer platforms as the most common method employed by prehistoric knappers (Callahan, 1979; Newcomer, 1971; Whittaker, 1994), and that interpretation will be adopted for the discussion below.

Typically, hard hammer percussion is cited as the technique employed in the completion of this preparation stage, commonly referred to as the 'roughing out' phase (Newcomer, 1971; Whittaker, 1994; Winton, 2005), or the 'Initial Edging' phase (Callahan, 1979). A final aspect of core preparation relating to soft hammer percussion concerns the abrading of striking platforms. The placement of blows on the edge of a core in soft hammer percussion (discussed below) means that the edge needs to be strong enough to pass the force of the blow on to the body of the core without simply being crushed (Mithen, 1999b: 393; Whittaker, 1994: 192). Abrading a platform, a feature commonly found on soft hammer flakes, reduces the risk of a crushed platform by removing any thin, sharp edges left over from prior removals, producing a rounder, thicker platform that is less likely to fail (Whittaker, 1994: 192).

The successful use of the soft hammer percussion technique to remove a flake requires attending to the same variables that contribute to hard hammer percussion removals. However, as I shall outline below, there are also ways in which attending to these variables in the use of the soft hammer percussion technique can be considered distinct. The distinctive nature of the variables stems largely from the fact that soft hammer removals aim to create ‘bending fractures’ in the raw material (as opposed to conchoidal fractures for hard hammer percussion), with the ‘soft’ qualities of the percussor providing an essential contribution in initiating fractures of this type (Cotterell & Kamminga, 1987: 683). In order to successfully initiate a bending fracture the knapper needs to take into account the following:

- Blow placement
- The blow angle
- The strength of the soft-hammer blow

Below, I will discuss how each of these variables affects the application of the soft hammer percussion technique.

6.4.1. Blow Placement

The ability to deliver accurate soft hammer blows plays an important role in the application of the soft hammer percussion technique (Callahan, 1979: 34). Indeed, the way in which a

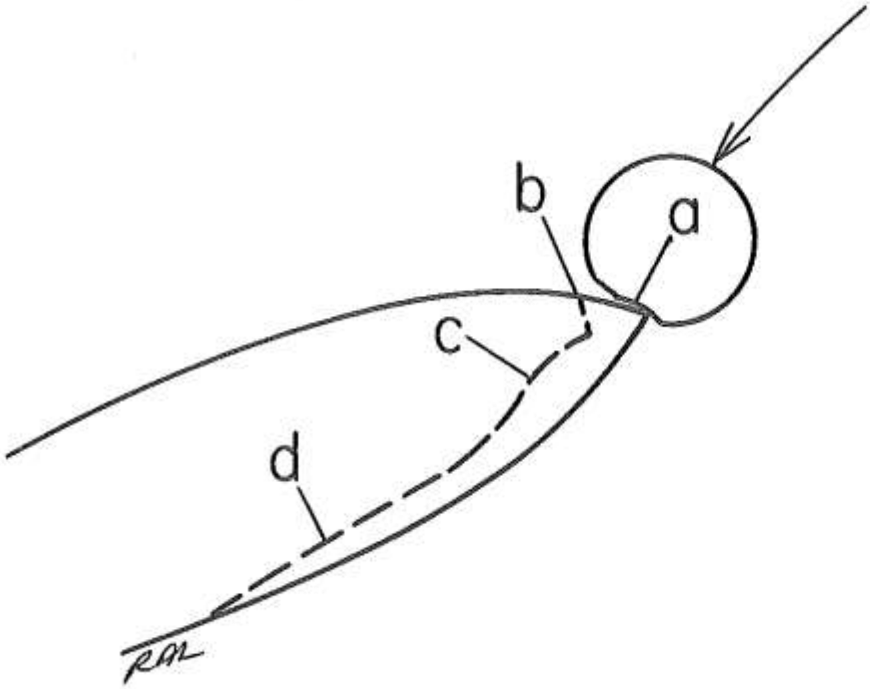


Figure 6.7: An illustration of a flake removal via Soft Hammer Percussion. The soft hammer (a) strikes the edge of the blank/core and initiates a bending fracture (b). The force of the percussion produces a diffuse bulb of percussion (c) and the fracture travels through the lithic material until a flake is detached (d) (after Whittaker, 1994).

blow is applied differs due to the utilisation of a different type of platform. Whereas the hard hammer technique involves striking a platform on the flat surface on the core (as in Figure 6.2), when applying the soft hammer percussion technique the platform is, in essence, the edge of the raw material itself (Newcomer, 1971: 89; Whittaker, 1994: 191, 196) (see Figure 6.7). It is the placement of a blow on the edge of a core using a soft hammer percussor that produces the desired morphology of the flakes when removed. Compare, for example, Figure 6.8 and Figure 6.9. While Figure 6.8 presents a typical soft hammer blow placement using the edge of the core as a platform, a typical hard hammer blow to the same core would exploit a different platform, and produce a shorter, thicker flake.

Figure 6.8: The soft hammer technique utilises the edge of the core as the striking platform. In the above example, the arrow indicates the ideal striking point for a soft hammer blow (after Whittaker, 1994).

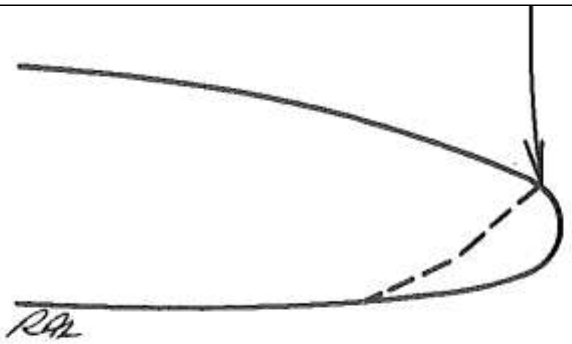


Figure 6.9: The effect of blow type on flake type. The hard hammer percussion technique applied to the same core as in Figure 6.1. Note that the different location of the striking platform, and that the flake removed is much thinner and shorter (after Whittaker, 1994).

For Whittaker, the selection of where a blow should be aimed for a given platform in soft hammer percussion depends on the location of the centreplane of the blank/core being struck, and he cites three feasible striking platform locations: i.e., above, on, or below the centreplane of the core (Whittaker, 1994: 197) (see Figure 6.10). Whittaker argue that for the best chance of success in initiating a bending fracture via soft hammer percussion, a blow needs to be delivered below the centreplane (Whittaker, 1994: 197). A blow delivered on, or close to, the centreplane is also feasible, and removes a longer, thinner flake, but the scope for error also increases, particularly in terms of the stresses placed on the core (Whittaker, 1994: 196-197).

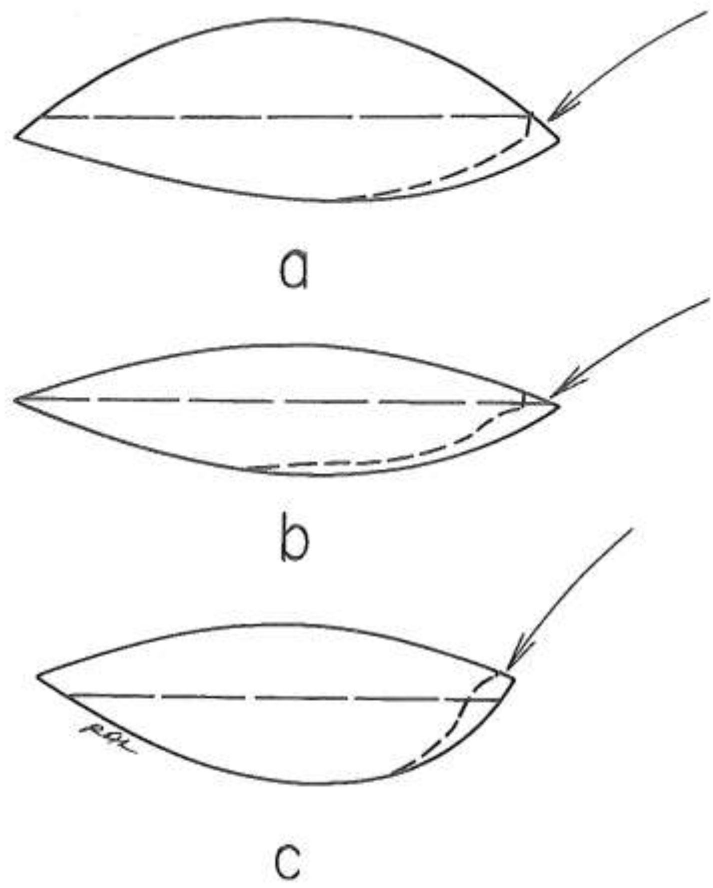


Figure 6.10: Three examples illustrating the effect of soft hammer blow placement on flake morphology for three different edge locations in respect to the centreplane. In (a), the striking platform is below the centreplane, and the resulting flake is removed from the lower surface of the core. In (b), the striking platform is on the centreplane. Selecting a striking platform of this type can have beneficial results in terms of removing longer, thinner flakes which run further over the surface of the core. However, platforms of this kind also require the most technical skill, and there are attendant risks in terms of adding stress to the core in blow application (resulting in a possible fracture of the core) or producing undesirable hinge, step, or overshoot terminations. Finally, a striking platform that is above the centreplane are undesirable and can result in a crushed platform or a short, hinged flake (after Whittaker, 1994).

Callahan disagrees slightly with this view, arguing that a blow delivered on the centre plane is preferable initially, and that one struck below the centreplane is more likely to produce the longer, thinner flake types mentioned above (Callahan, 1979: 34). For both researchers, however, the selection of a striking platform above the centreplane typically represents an error, with short flakes being removed, a high risk of hinging/step features (Whittaker, 1994: 197) and an increased risk of fracturing of the blank/core (Callahan, 1979: 34)

Errors in blow precision can result in undesirable features on a prepared core. Whittaker, for example, notes that a blow that is placed too far in from the biface edge will result in an 'edge-bite' fracture which 'initiates well in from the intended platform' (Whittaker, 1994: 190) which can effect later removals within an applied method. Similarly, as mentioned above, blows that are ill placed in relation to the centreplane will fail to produce a desired soft hammer flake while also risking a fracture in the body of the core itself.

6.4.2. Blow Angle

The angle of blow for the soft hammer percussion technique differs when compared to hard hammer percussion. Whereas for the hard hammer percussion technique the angle of blow is always less than 90° (see Figure 6.4), in the case of soft hammer percussion it often exceeds 90° (Whittaker, 1994: 187, 191) (see Figure 6.11).

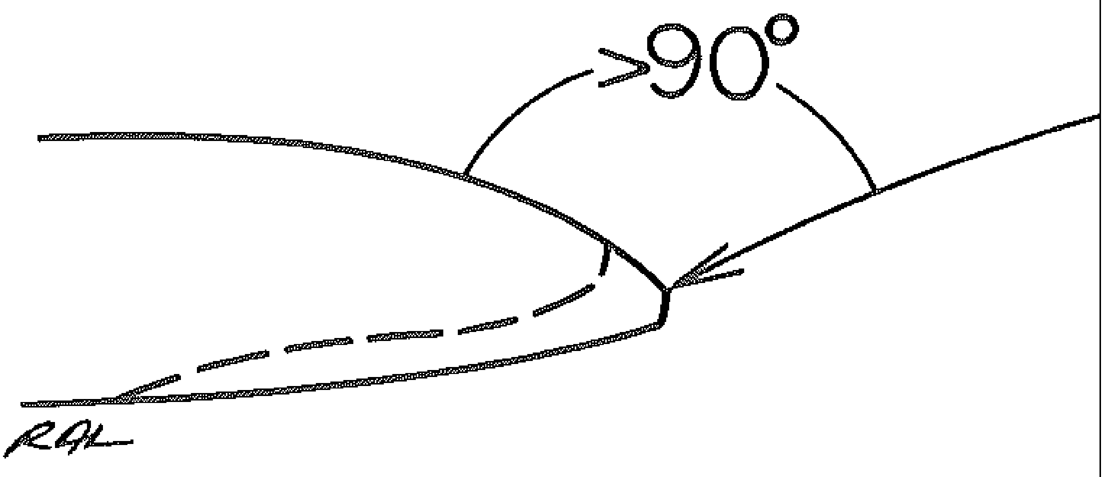


Figure 6.11: Soft hammer percussion blow angle. A typical blow angle for the soft hammer percussion technique measured from the face of the core exceeds 90° (Whittaker, 1994).

Though noting that there are difficulties in obtaining precise measurements of blow angle due to the curvature of the core, Whittaker proposes that a typical blow angle for a soft hammer removal is between 100° and 110° in relation to the upper surface of the core, or between 130° and 150° when measured from the centreplane (Whittaker, 1994: 191), while Callahan similarly suggests and angle of 130° from the centreplane of the core (Callahan, 1979: 34). Whittaker likens this angle of blow as akin to one aimed directly from above on a typical flat hard hammer platform, roughly parallel to the initiated fracture (Whittaker, 1994: 191).

As with blow placement, misjudging the angle of the blow can have a deleterious effect on the task at hand. Using a blow angle that is too steep can produce only a short, thick flake (as in Figure 6.9) or no flake at all, while applying a blow with an angle that is too obtuse carries the risk of fracturing the body of the core or producing undesirable overshot or hinged flakes (Callahan, 1979: 34).

6.4.3. Blow Strength

Finally, the soft hammer percussion technique requires the application of a much harder blow for the successful detachment of a flake when compared to hard hammer percussion (Whittaker, 1994: 187, 192), which arguably renders the task more challenging to learn and master. This fact can have negative connotations for controlling the other variables in the application of a blow (i.e., blow angle and placement), due to the fact that manual/technical control typically diminishes as the knapper attempts to apply more force (Whittaker, 1994: 193).

Indeed, misjudging the blow strength can adversely affect the outcome of the task. Assuming a platform is accurately struck at the required angle, the application of too soft a blow can result in a hinged flake, while striking the platform with too much force can crush the platform, produce a step-fracture termination, or even risk fracturing the body of the biface itself (Whittaker, 1994: 193). Soft hammer percussion therefore requires the knapper to judge the blow strength in terms of delivering it within a desired range in terms of force, but on average the force required is greater than for hard hammer removals.

6.5. Establishing The Specificity of The Task Domains

In addition to consulting the relevant sources (i.e., accounts of expert knappers and experimental work into fracture mechanics) to clarify the nature and extent of the information-processing problems salient to the two techniques under consideration, Tooby and Cosmides propose that a task analysis should establish, as far as is possible, that the particular information-processing problems identified are not implicated in other adaptive behaviours (2005: 28). So though the information-processing problems outlined above (i.e., delivering a precise blow, at a precise angle, and with a desired strength) need to be solved in the application of both the hard and soft hammer techniques, whether they constitute distinct task domains is still open to question.

One can confidently state that sundry other skills are implicated in both the hard and soft hammer techniques, and that some of those skills will predate the ancestral split between the human and ape lines. Further, such skills may have such a general application that they are associated with multiple adaptive benefits (e.g., the visual assessment of 3-D objects, using the hand/fingers to grasp and manipulate objects).

Though such general skills are utilised in the application of hard and soft hammer percussion, any associated cognitive structures need not be specifically attuned to solving the specific information-processing problems of the task domains (or, indeed, for any of the other numerous manual tasks in which they are implicated). For the purposes of the current task analysis, one needs to consider whether the information-processing problems outlined above for each technique can be interpreted in a similar light: i.e., do they have a similarly general application, to the extent that they cannot be viewed as exclusive to the techniques being analysed. For comparative purposes, however, the two techniques require different approaches.

For hard hammer percussion, one needs to consider whether pre-existing cognitive structures that evolved to mediate other percussive behaviours are being co-opted in the process of learning/applying the technique. This involves examining possible percussive behaviours that may predate hard hammer percussion. Primatological data can be informative in this respect to provide models for how percussive tasks used in subsistence activities in species that do not utilise true hard hammer percussion spontaneously in the wild[35].

For soft hammer percussion, in contrast, one needs to consider whether possible pre-existing cognitive structures relating to an already well-established percussive behaviour linked specifically to the fracture of lithic materials (i.e., hard hammer percussion) are being redeployed in the learning/use of the technique. One therefore needs to compare these two task domains to assess whether there is an adequate distance between the information-processing problems involved to prompt the evolution of cognitive mechanisms specifically related to soft hammer use.

6.5.1. The Specificity of the Hard Hammer Percussion Technique

Percussive behaviours are not unique to either *Homo* sapiens, the *Homo* line in general, or even the great apes. For example, percussive behaviours involving stone tool have been documented in Capuchin monkeys in the wild (Visalberghi, et al., 2009), while sea otters have been documented using stone tools to crack open molluscs (McGrew, 2004: R1046). There is a real possibility, therefore, that pre-existing cognitive structures relating to such behaviours were present in the cognitive architecture of our ancestors prior to the emergence of hard hammer percussion.

For the purposes of examining the extent to which hard hammer percussion presents distinct problem types when compared to other percussive behaviours an assessment of the

[35] Some experiments where researchers have attempted to teach a bonobo to employ the hard hammer technique have enjoyed a degree of success, though a general consensus remains that apes are not capable of utilising hard hammer percussion with the same level of skill as Oldowan hominids (Pelegrin, 2005; Toth & Schick, 2007).

manual skills of the extant great apes can be potentially informative. Research conducted by Byrne (2005) is particular apt in this respect. Byrne collated evidence of manual skills displayed in the extant great apes in an attempt to identify the manual and cognitive skills that may have been precursors for hominid tool use. In doing so, he identified those skills that are typically associated with tool production in *Homo sapiens*, and then assessed the primatological literature for evidence of their occurrence in the manual behavioural repertoire of the great apes (i.e. chimpanzees, gorillas and orang-utans).

The only skills that Byrne identifies as possible precursors to tool use which are also unambiguously implicated in the use of the hard hammer percussion technique are: precision handling, bi-manual role differentiation, and the accurate aiming of powerful blows. Amongst the various behaviours considered by Byrne, the one that is arguably most closely related to hard hammer percussion, and which encapsulates all the traits mentioned above, is nut cracking[36], which is a behaviour documented in chimpanzees (Boesch & Boesch, 1982)[37].

From Byrne's analysis, it is apparent that hard hammer percussion and nut cracking share pertinent common ground in terms of information-processing problems. Both tasks require a degree of appreciation of the raw material in selecting an adequate hammerstone for the

[36] The other examples are worth mentioning briefly here, if only to emphasise their conceptual distance from hard hammer percussion, despite exhibiting one or more of the traits cited by Byrne. For example, it was noted that Chimpanzees display precision handling in the making ant dipping wands, Gorillas use deft folding to avoid sting-covered areas of leaves, and that Orang-utans have displayed an impressive array of precise and delicate skills in captivity (such as pouring liquid into a narrow neck vessel and threading rope through metal rings) (2004: 36-38). These, and similar other examples, do not, however, warrant further comparison with hard hammer percussion.

[37] Another task that share some similarity is fruit smashing (Marchant & McGrew, 2005), though the focus here will be on nut cracking specifically. According to Byrne, there is no evidence suggesting gorillas and orang-utans in the wild employ manual skills involving the application of accurate, powerful blows (though evidence from captive Orang-utans suggests that they possess the cognitive ability to engage in such behaviours) (2004: 38, 39). Additionally, the utilisation of accurate, powerful blows is not ubiquitous even in chimpanzee populations; it has only been documented in West African chimpanzee populations (where it is widespread but not universal) (Toth & Schick, 2009: 296).

task at hand (2004: 35); both tasks employ the dominant hand to hold a stone percussor (i.e., a hammerstone) and use it to strike a precise blow (Byrne, 2004: 36); and both tasks require learning and practice plays a significant role in the acquisition of the necessary skills (Byrne, 2004: 40). Indeed, for some researchers there are no major differences in qualitative terms between the two behaviours. Joulian, for example, makes this point after comparing the respective *chaîne opératoire* for nut cracking and Oldowan-style flake production (Joulian, 1996: 187).

Joulian's conclusions, however, can be challenged by subsequent research indicating a higher degree of sophistication than previously assumed in the percussive behaviours of Oldowan hominids. His *chaîne opératoire*, for example, assumes that the conceptual schema of Oldowan hominids was poor, as was their ability to adapt percussive behaviours to different raw materials (1996: 185). This assumption has been challenged by excavations at the 2.34 million year old site of Lokalalei 2C, Lake Turkana basin, Kenya (Delagnes & Roche, 2005: 437). Exceptional levels of preservation at this site have allowed archaeologists to gain insights into the percussive behaviours that were engaged in, particularly in terms of revealing a hitherto unexpected degree of complexity. Delagnes and Roche suggest that Lokalalei 2C presents evidence of raw material testing prior to transport (Delagnes & Roche, 2005: 444-445), while evidence from the 2.3million year old site of Omo, Ethiopia, point to an ability to adapt percussive behaviours to different raw material types (de la Torre, 2004a). Indeed, a converse case to Joulien's can be made that hard hammer percussion is distinct from nut cracking, from the initial selection of raw material, to the strength, precision and angle of the required hammerstone blow, all of which stem directly from the need to exploit conchoidal fracture to achieve the desired product (i.e., a sharp flake).

The different problem types involved in the selection of raw material, for example, become evident if one compares the two task domains. For hard hammer percussion, as mentioned previously, the important factors to consider are raw material quality (including how well the material flakes, and how durable the flakes are once removed) and whether the core exhibits favourable morphological features (such as exterior platform angles conducive to flake removal) (Braun, Plummer, Ferraro, et al., 2009; Nonaka, et al., 2010). For nut cracking, on the other hand, the selection of raw material concerns how well suited the raw material is to the task of crushing a nut. For the hammerstone, this will take into account factors such as the ease with which the stone tool can be wielded (is it too big to grasp, or too heavy to wield, for example) and whether it is of adequate weight to crack a hard shelled nut, while for the anvil the overall morphology will be assessed, with largely flat surfaces being preferred, occasionally with certain favourable features such as divots to house the nut (Bril, et al., 2009; Foucart, et al., 2005).

The reasons that lie behind the selection, or rejection, of raw material in each case explains why the two task domains can be considered distinct; both take into account certain properties of the raw material in making a selection, but they do not focus on the same properties. For Oldowan hominids, the desired product of hard hammer percussion was a sharp flake, which can be used for further tasks such as cutting and slicing (Roche, et al., 2009: 137; Stout & Chaminade, 2007: 1092). If a raw material is intentionally selected in terms of how amenable it is to this task, an understanding of how stone fractures is therefore required prior to selection (Stout & Chaminade, 2007: 1092). With chimpanzee nut cracking, on the other hand, the desired end product is a crushed shell, and an extracted nut, and the raw material needs to be suitable for achieving this end.

In addition to guiding raw material selection, the varied aims of the two task domains also dictate the different ways the variables are attended to in the two tasks. Again, the need to exploit the conchoidal fracture properties of the raw material in hard hammer percussion is cited at the major influencing factor on how the variables are controlled, as well as the fact that two or more of these variables need to be attended to simultaneously with the dominant and non-dominant hands engaging in different tasks (Bril, et al., 2009: 70; Foucart, et al., 2005: 156). As with raw material selection, comparing nut cracking and hard hammer percussion provides good evidence that blow precision, blow strength, and blow angle are indeed information-processing problems that are specific when performed within the hard hammer percussion task domain.

The ability to deliver a precise blow is clearly important in both hard hammer percussion and nut cracking. But one may question, firstly, whether the same level of precision is required in both tasks, and secondly, whether in both cases the precise blow needs to be co-ordinated with other factors to achieve the desired end. Though chimpanzees use precision blows, some argue that there is a sense in which those used by Oldowan hominids in utilising the hard hammer percussion technique need to be much more precise (Byrne, 2004: 40). Nut cracking, in contrast, could be viewed as akin to bi-polar split breaking, where an object steadied by the non-dominant hand is struck with a blow from the dominant hand from above. For Pelegrin, hard hammer percussion needs to be much more precise than the bi-polar technique, both to guarantee successful flake removal, and to ensure the flake removed is of the desired sort (2005: 25).

Considering blow strength, the fact that all the variables can impinge on the success of the application of the hard hammer percussion technique individually means that the connotations of misjudging blow strength can affect the success of the task differently than is the case for nut cracking. In nut cracking, blow strength can be undershot, or overshot: if a blow is too weak, one simply tries again with an more forceful blow; if a blow is too strong, the nut will still crack, even though the kernel inside the hard shell may suffer some crushing (Bril, et al., 2012 61). For hard hammer percussion, however, the ability to accurately judge the requisite blow strength, in co-ordination with other factors, can affect the success of the task. As mentioned above, too weak a blow can result in a hinge/step termination that complicates further flake removals. Meanwhile, a tenancy to overestimate the blow strength required can compromise the accuracy of the blow placement (Nonaka, et al., 2010); maintaining the precision of the blow, and the correct blow angle, therefore becomes more difficult as blow strength is increased.

Considering blow angle, in the case of hard hammer percussion this is a crucial variable that needs to be taken into account for the successful removal of a flake. Striking from directly above (i.e., with a blow angle of 90°) is rarely required (in contrast to a nut cracking task), and the choice of blow angle, and how it is applied and co-ordinated with the point of impact and the blow strength, contribute directly to the success of the task. For nut cracking, the blow angle is not such an active variable. Though the angle of blow can contribute to the success of a nut cracking task (Boesch & Boesch, 1982), it is true to say that blows from directly above are optimal in most instances, since angled blows are unlikely to prove successful in crushing the nut between the anvil and the hammerstone (and may result in the nut shooting out from between the hammer and the anvil on impact). Experiments into nut cracking movements in captive chimpanzees conducted by Foucart *et* *al*, for example, recorded little variation in the strike angle during nut cracking tasks, though the morphology of the anvil did affect this to an extent; a tendency to strike a more vertical blow was evident when using anvils with a flat anvil than for one with a cavity (Bril, et al., 2009: 233; Foucart, et al., 2005: 154).

Finally, it is worth noting that the archaeological evidence provides some suggestions that the hard hammer percussion tasks were executed in some of the earliest archaeological contexts with a high degree of expertise. At Lokalalei 2C, for example, Delagnes and Roche observe that there is scant evidence of failed blows on the cores, despite the fact that the hominids at this site were employing extended removal sequences (some refits record up to 30 flakes from a single core, giving ample opportunity for errors on the part of the knapper) (Delagnes & Roche, 2005: 543; Roche, et al., 1999: 59). This suggests that the variables involved in hard hammer percussion at this site were being controlled with few errors. In contrast, experimental work with chimpanzees and examinations of the chaîne opératoire of nut cracking both suggest that failed blows are a common feature of this behaviour (Bril, et al., 2012 ; Foucart, et al., 2005; Haidle, 2009; Joulian, 1996). One might surmise from this that hominins invested more effort over time in avoiding failed blows in hard hammer percussive tasks, which may stem from factors such as a need to utilise raw materials optimally due to scarceness.

Comparing the two problem domains of nut cracking and hard hammer percussion therefore suggests that the information-processing problems salient to the task domain of hard hammer percussion differs from nut cracking in important ways. Indeed, if one imagines two groups of hominins trying to benefit from access to the adaptive advantages linked to the use of hard hammer percussion, a groups of hominins with cognitive structures geared towards solving the specific problems of hard hammer percussion would, over time, arguably have an adaptive advantage over a group trying to access the same advantages employing cognitive structures that evolved to solve a related task such as nut cracking.

6.5.2. The Specificity of the Soft Hammer Percussion Technique

When seeking to establish that the information-processing problems associated with the soft hammer percussion technique are not implicated in other adaptive behaviours, the hard hammer percussion technique arguably presents the most relevant task domain for comparative purposes. Scant evidence exists for behaviours that equate to those utilised in soft hammer percussion in any of the extant great apes. Indeed, if one envisages billet use as the primary means of soft hammer percussion, the only apparent analogues are chimpanzee 'clubbing' behaviours using woody material to ward off threats (i.e., snakes) or intimidate rivals, and 'pounding' behaviours using woody materials for subsistence purposes (e.g., breaking open bee nests) (Whiten, et al., 2009: 4). In such example, however, the overall aim of soft hammer flake removal is entirely lacking, and none of the associated variables discussed above are attended to as a result. Though they may share some physical actions in an approximate sense, therefore, one can safely state that, in cognitive terms, the two tasks share common ground in only a superficial sense.

Indeed, it is noteworthy that in experiments aimed at elucidating the percussive behaviours of the extant great apes no attempts have been made to test behaviours beyond those of basic hard hammer percussion, which itself has enjoyed varied success (McGrew, 1992; Schick, et al., 1999; Toth & Schick, 2009; Toth, et al., 2006). One can therefore state with some certainty that any cognitive precursors to the behaviours implicated in soft hammer percussion will be found in the *Homo* line. The remainder of this section will therefore be concerned with examining the extent to which the information-processing problems of soft hammer percussion represent a distinct task domain, or, conversely, whether any pre-existing cognitive structures relating to hard hammer percussion could be co-opted to solve the problems concerned.

Perhaps the most often cited area that soft hammer percussion is seen as distinct from hard hammer percussion concerns the incorporation of the soft hammer billet itself. The use of a billet will have connotations for the biomechanics of blow delivery, since the soft hammer presents an extension of the arm. In such instances, the precise delivery of blows requires slightly different skills when compared to hard hammer percussion, where the hammerstone is largely synonymous with the hand of the knapper. However, both the ubiquity of billet use and the degree to which billet use differs from hammerstone use be brought into question. As noted by Wenban-Smith in his study of various knapping episodes at Boxgrove, episodes of soft hammer percussion can involve the use of soft stone hammers rather than billets (1999), and the biomechanics of the task (though not the fracture mechanics or the associated variables) would be more comparable to hard hammer percussion in such instances.

Indeed, even if one is willing to accept that billet use was the predominant means of soft hammer flake removal, one can still question whether the task of billet blow delivery is distinct enough to require dedicated cognitive structures. Since, as noted above, competence in hard hammer percussion is a prerequisite of the use of the soft hammer percussion technique, one could argue that learned behaviours (potentially mediated by dedicated cognitive structures) relating to the delivery of precise blows would already be present in an individual learning soft hammer percussion.

Beyond any biomechanical factors associated with billet use, one could argue that the task domain of soft hammer percussion is specific in terms of type of fracture the knapper aims to produce (i.e., bending fractures that produce typical 'soft hammer' flakes) in accordance with the constraints inherent in the raw material (Callahan, 1979; Newcomer, 1971; Whittaker, 1994). As outlined above, the need to instigate a bending fracture requires a different blow with distinct attributes: i.e., a blow delivered with a lot of force, at a specific angle and placed with precision on a suitably prepared/selected 'edge' striking platform.

On one view, these variables, and the way the knapper must attend to them in conjunction to remove soft hammer flakes, are distinct from the variables attended to during hard hammer percussion. On another view, however, one could argue that, though the variables differ in certain ways between the techniques, they share many commonalities as a manual task. This point becomes particularly apposite if one considers soft hammer percussion within a wider context of the extent to which two task domains of *any* kind can differ. If one compares, for example, soft hammer percussion with a domain like mate selection, the information-processing problems involved are clearly more disparate and share little meaningful common ground, and are therefore unlikely to rely on the same cognitive processes.

The conceptual distance between two techniques that focus on learned percussive behaviours applied in the fracturing of lithic materials seems much less in such a light. Indeed, whereas one can point to the aim of fracturing lithic materials to obtain flakes as a distinctive aspect of hard hammer percussion when compared to nut cracking, one cannot do likewise when comparing the soft and hard hammer percussion techniques, which share this common aim.

The crux of the issue here is whether the soft hammer percussion technique presents information-processing problems distinct enough for the selection over time of dedicated cognitive structures in the *Homo* line to address them specifically. Though soft hammer percussion has the requisite chronological depth, and a strong argument can be made that it was a behaviour that recurred through prehistory, questions remain as to whether the task domain of the technique shares commonalities with hard hammer percussion to the extent that pre-existing cognitive structures could be co-opted to facilitate the soft hammer learning process[38]. Indeed, one aspect of the cultural/social context in which the soft hammer technique was purportedly learned needs to be considered: namely, that the acquisition of soft hammer percussive skills in prehistory was most likely coupled with (and dependant on, as per the interpretation adopted above regarding core preparation) a prior familiarity with hard hammer percussion.

Arguably, the phenotypic expression/development of percussive behaviours in the past would therefore not have begun with the soft hammer technique in any context. Soft hammer percussion behaviours were not learned in a vacuum; arguably all knappers would have experience of prior behaviours in a related (though not necessarily synonymous) task domain (i.e., hard hammer percussion). And this prior learning would have provided a skill set that could be usefully reapplied when using soft hammer percussion. The knapper would already be familiar with the application of precise blows and the adjustment of blow

[38] Assuming, of course, that the results of testing support the hypothesis that such cognitive structures exist in the human cognitive architecture in relation to hard hammer percussive behaviours.

angle to suit the requirements of a given removal, while the delivery of the forceful blows required in soft hammer percussion will be a much easier task if blow delivery with less force has already been extensively practiced.

The upshot of here is that two broad interpretations can be proposed regarding the question of whether soft hammer percussion is a technique whose learning is mediated by dedicated cognitive structures. The first interpretation is that the soft hammer percussion technique does not differ substantially enough from hard hammer percussion in terms of information-processing problems, and the engagement and learning of soft hammer percussion is mediated by structures that evolved to solve problems in task domains relating to another percussive behaviour (i.e., hard hammer percussion). The second interpretation is that soft hammer percussion does represent a distinct task domain in terms of information-processing problems, the solution of those problems is mediated by dedicated evolved cognitive structures, but the expression of those structures relies on prior triggering in terms of pre-acquiring percussive skills in a related task domain.

Ultimately, only the testing process can give any indication as to which of these interpretations is more accurate, but note that the acknowledgement of the inter-connectedness of the two techniques is important in this respect. If one is willing to accept that no prehistoric knapper would have been exposed exclusively to the information-processing problems associated with the soft hammer percussion technique, then the prior learning of hard hammer percussion will need to be incorporated into the testing process. To focus exclusively on soft hammer percussion risks bypassing possible cognitive 'triggers' that might have contributed much to the learning process in prehistoric contexts.

6.6. Conclusion

In conclusion, the aim of this chapter was to perform a task analysis for the hard and soft hammer percussion techniques in order to identify the information-processing problems that need to be solved in their utilisation. I began by drawing on evidence from expert knappers and experimental fracture mechanics to identify three key variables that need to be controlled in the application of hard hammer percussion. The information-processing problems associated with the control of the blow angle, the precise placement of the blow on the platform, and the blow strength were identified as salient to the hard hammer percussion technique in exploiting raw materials that exhibit conchoidal fracture. Similarly, for soft hammer percussion I argued that the same variables need to be attended to, though with important differences, as dictated by the need to engender 'bending fractures' in the task domain of soft hammer percussion, rather than conchoidal fractures.

I then examined whether the information-processing problems of the two tasks could be considered specific to their respective domains, arguing that different approaches were required for each in this area. For hard hammer percussion I assessed the manual skills of the extant great apes to attempt to examine whether those information-processing problems associated with the key variables were specific to the hard hammer percussion task domain. Of the skills evident in the behavioural repertoire of the great apes, only chimpanzee nut cracking had the prospect of sharing information-processing problems with hard hammer percussion in terms of applying accurate, powerful blows with a hammerstone.

However, I further argued that information-processing problems that comprise nut cracking and hard hammer percussion differ in terms of the criteria employed to select raw material, the precision with which blows need to be applied, and the fact that hard hammer percussion necessitates the instantaneous co-ordination of three variables, each of which can cause failure if misjudged. The ability to a strike precise, angled blow with a desired weight, given an initial assessment of the contingencies presented by core morphology, therefore represent information-processing problems that are both salient and unique to the hard hammer percussion technique. Arguably, therefore, there are sufficient differences between the hard hammer percussion and nut cracking task domains to propose that cognitive structures may have evolved specifically for solving the problems relating to the former, particularly given the significant time frames over which such changes could have occurred.

Regarding soft hammer percussion, I argued that, though soft hammer percussion presents distinct problems when compared to hard hammer percussion, one needs to recognise that both are essentially percussive behaviours with an inherent overall aim of fracturing lithic materials. Further, I argued that soft hammer percussion is not a technique learned in isolation, but a task that is engaged in only after prior grounding in hard hammer percussion. I concluded that the learning of the soft hammer percussion technique may therefore draw on pre-existing cognitive structures geared towards the facilitation of solving problems intrinsic to hard hammer percussive behaviours, and that this possibility needs to be acknowledged and incorporated into the process of test formulation.

Chapter 7: A Task Analysis of Stone Tool Production Methods

7.1. Introduction

The aim of this chapter is to perform a comparative task analysis of the biface and Levallois methods. For the biface and Levallois methods, this will initially involve providing a detailed account of the two methods under consideration, drawing on both reconstructions based on archaeological materials (where available) and the interpretations of modern knappers as to how the methods are implemented. Note that the characterisations of the two methods provided will draw upon an interpretation of the task domain where intention plays a prominent role.

In attempting to identify the salient information-processing problems of the method task domain, the potential pitfalls of uncritically extrapolating information-processing problems from modern interpretations of past knapping episodes need to be considered. I argue that the information-processing problems of the method task domain can vary depending on which of the rival interpretations one adopts regarding the form and degree of intention on the part of the knapper. In addition, I consider the obstacle the social context of learning (as a largely unknown aspect of the method task domain) presents to any attempt to clarify the salient information-processing problems. Despite the potential pitfalls relating to rival models of intent and the paucity of data relating to the social context of learning, I expound an argument below that adopting the methodology of Evolutionary Psychology allows multiple interpretations of the method task domain to be tested.

In describing the salient information-processing problems of the method task domain I propose that those cognitive capacities that facilitate the attainment of expertise, as indicated by an ability to execute sequences of flake removals in accordance with both short-term and long-term goals, define the task domain. Specifically, I argue that the embedding of retrieval structures or 'constellations of knowledge', and the ability to 'think through' removal sequences can bolster the method learning process.

Finally, I address the issue of specificity. As stated previously, an important step in the task analysis involves establishing, as far as is possible, that the particular information-processing problems identified are not implicated in other adaptive behaviours (Tooby & Cosmides, 2005: 28). This criterion is, on first reading, problematic given that the proposed information-processing problems exhibit a degree of generality, to the extent that they would have been implicated in a wide variety of tasks. However, I argue that the specificity of the method task domain is maintained due to their utilisation in association with a stone tool production technique.

7.2. The Biface Method

The biface method is both complex and technically demanding, as indicated by experimental replication and the re-fitting of debris from archaeological sites where handaxes were produced (Bergman & Roberts, 1988; Mithen, 1999b; Schick, 1994: 584). Modern knappers and lithic researchers typically delineate the biface method into a number of distinct stages (Mithen, 1999b; Newcomer, 1971; Whittaker, 1994; Winton, 2005), incorporating multiple flake removals (i.e., a minimum of twenty flake removals and a maximum of approximately one hundred (Chazan, 2012: 198-199)), and necessitating the skilled application of both the hard hammer and soft hammer percussion techniques to achieve different goals at various stages of the production process (Newcomer, 1971: 95; Winton, 2005: 112).

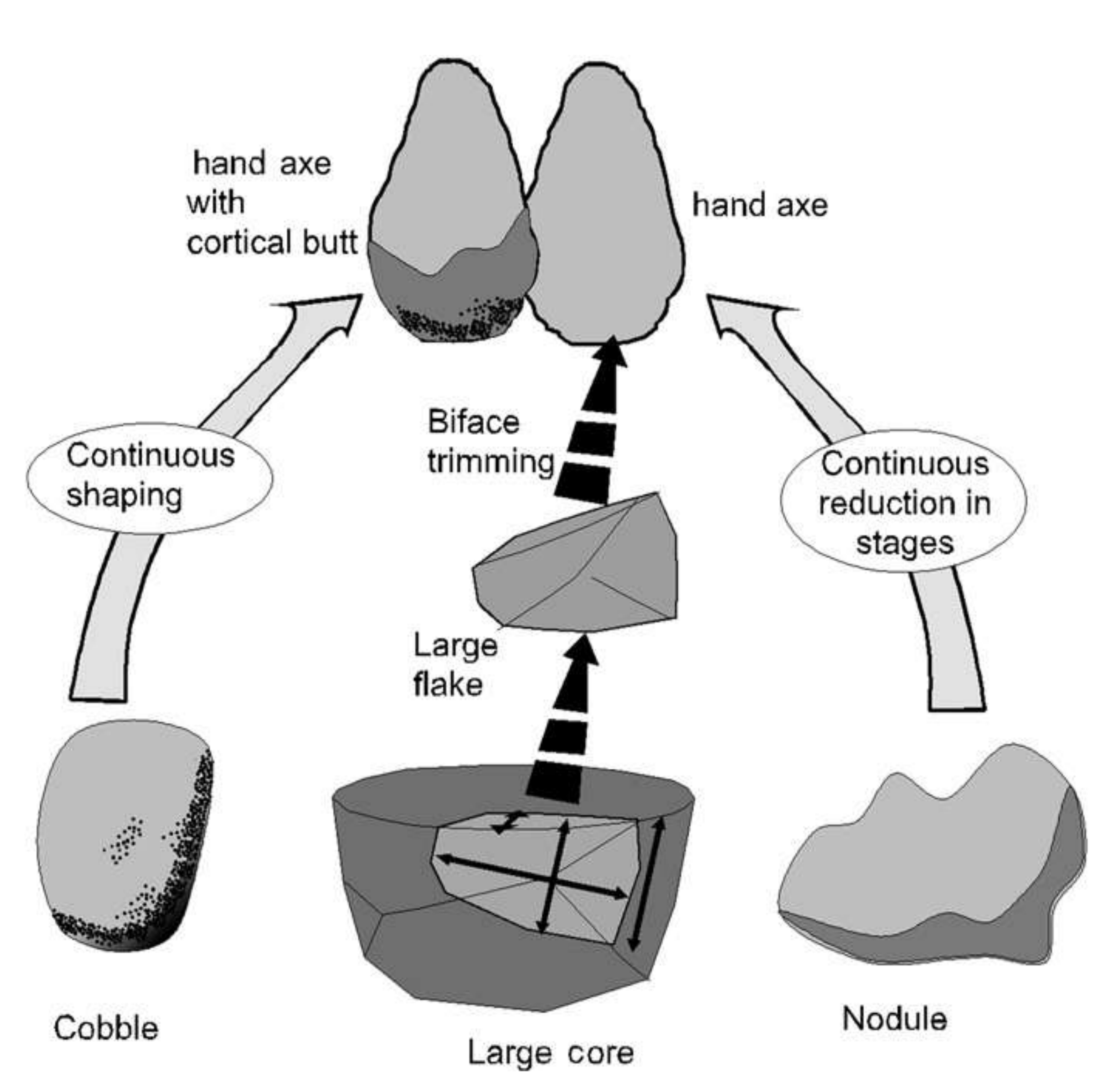


Figure 7.1: Illustration of three different pathways to biface manufacture utilising different raw material morphologies as a starting point (after Gowlett, 2009: 406)

Though the focus here will be largely on the reduction process, one acknowledges that the preliminary selection of knapping tools and raw materials could also be included within the wider task domain of the biface method. Both hard and soft hammers, for example, need to be selected with a view to their suitability for the task. Similarly, the raw material that is used for biface production needs to be selected for certain attributes. Raw material selection may be as straightforward as selecting a cobble or flake which is large enough and flat enough for bifacial reduction to be applied (see Figure 7.1). However, in some instances, such large, flat flakes might need to be struck from a boulder core which, as Schick notes, is a task that would be beyond the skills of a novice (Schick, 1994: 584)[39]. Further, numerous 'fundamentally different, innovative, and sophisticated methods' of flake blank production can be identified archaeologically (Sharon, 2009a: 335). Sharon (2009a), for instance, cites seven examples of such methods: bifacial, sliced slab, cobble-opening (*éclat entame*), Kombewa, VictoriaWest, Tabelbala-Tachenghit, and Levallois.

Another factor to consider regarding raw material selection is the initial morphology, which might include an anticipation of how well it will withstand the stresses of the bifacial method (Shipton, et al., 2009b: 783). Indeed, based on the archaeological evidence from the site of Isampur Quarry, India, Shipton *et al* argue that the initial blank morphology can determine which type of bifacial tool the knapper attempts to produce (i.e., biface or cleaver) (2009b: 770). Similarly, at Gesher Benot Ya'aqov, Israel, Goren-Inbar *et al* argue that other types of tool (notably, 'massive scrapers') were manufactured from blanks deemed unsuitable for producing bifacial tools (2008: 703).

7.2.1. Edged Blank/Roughing-out Stage

[39] This assertion is support to an extent by an ethnographic case study documenting large flake blanks being struck from boulder cores via a double handed strike from above the head with a hammerstone weighing 5-10kg (Stout, 2002: 697).

The application of the biface reduction method begins with the ‘edged blank’ or ‘roughing-out’ stage. Here, the knapper employs hard hammer percussion to remove relatively large flakes from around the periphery to produce a bifacial ‘blank’ (Mithen, 1999b: 393; Whittaker, 1994: 201). Removals of between ten and twenty flakes are made alternately from both faces of the biface, with the aim of quickly removing large amounts of superfluous raw material and producing a ‘unit’ of stone which exhibits platforms suitable for further removals in the next stage (see Figure 7.2) (Whittaker, 1994: 202; Winton, 2005: 110). The intended end product is a blank which is approximately twice as wide as it is thick, with the edges exhibiting an angle of between 50°-80° (see Figure 7.3, section a) (Whittaker, 1994: 202).

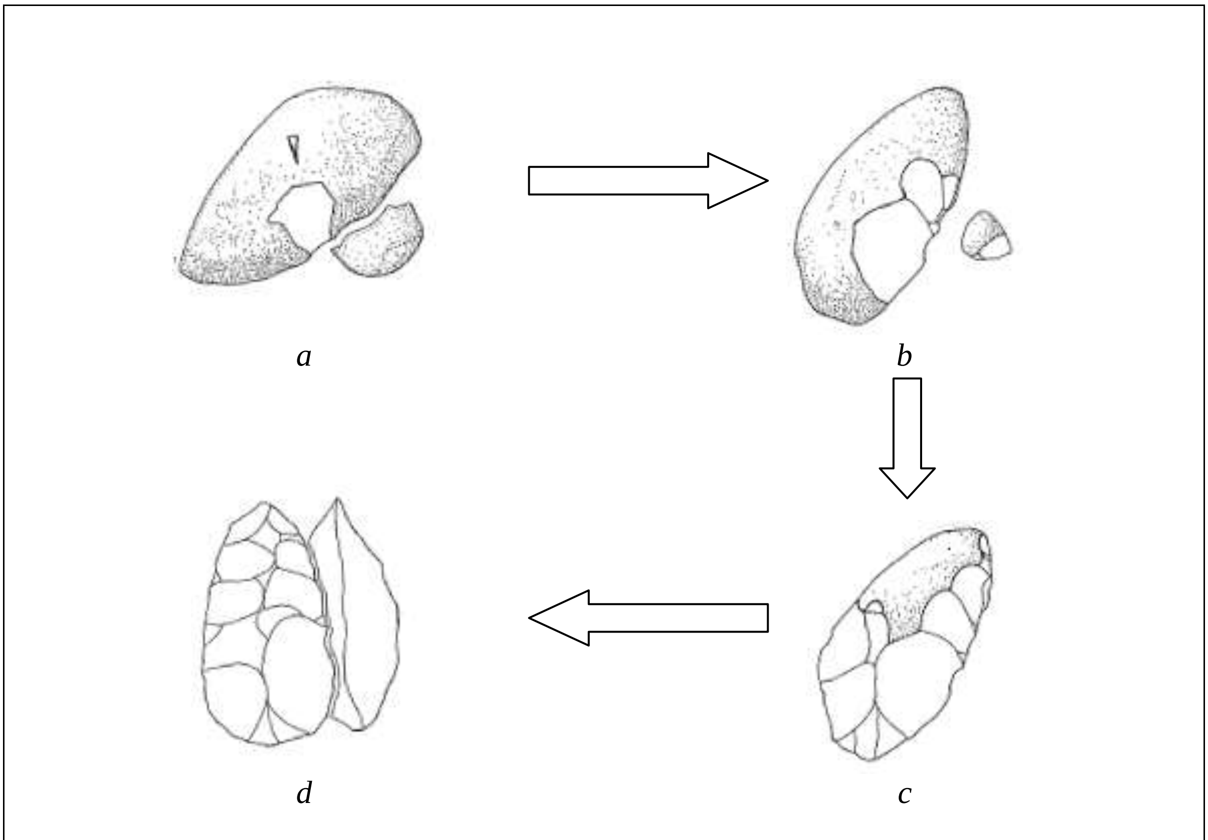


Figure 7.2: The hard hammer roughing-out stage. Illustration of the hard hammer ‘roughing-out’ stage of the biface method (a-d) (after Gamble 1999: 131).

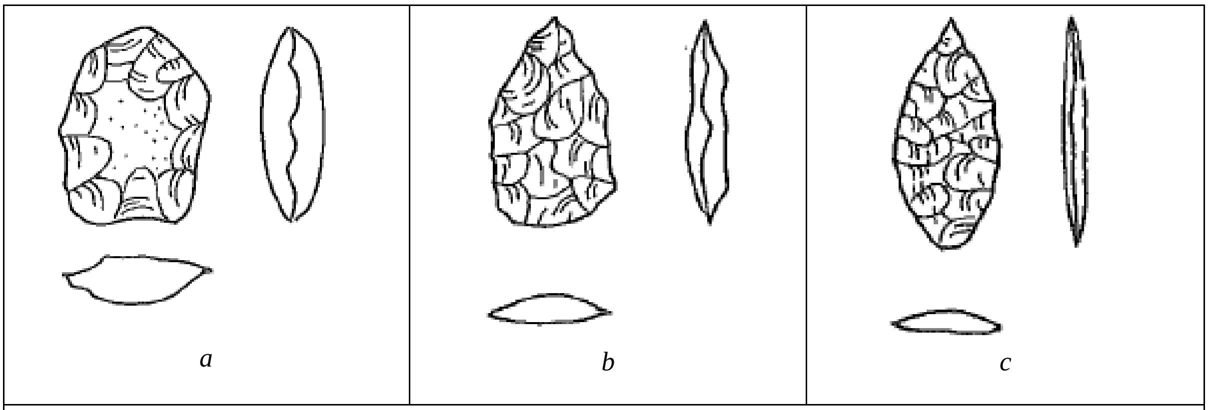


Figure 7.3: Idealised end products of the three stages of the biface method. Illustration of the idealised end products of the three stages of the biface method, including a: the Edged Blank/Roughing-Out Stage; b: the Preform Stage; and c: the Refined Biface/Finishing Stage (after Whittaker 1994: 200).

Though it may appear merely a preparatory step, the edge blank/roughing-out stage has important connotations for the ongoing success of the biface method. As Winton states:

> 'Failure to prepare a suitable handaxe rough-out during the first stage of knapping predetermines the outcome of later attempts to thin and shape the tool and to this extent the first phase of flaking is the most crucial.' (2005: 113)

7.2.2. Preform Stage

The next stage is the preform stage, where the focus is on 'primary thinning' of the unit produced in the roughing-out stage (Whittaker, 1994: 202). It is with this stage that the hard hammer technique gives way to the use of a soft hammer of antler, bone or wood (Crabtree, 1970; Mithen, 1999b: 393; Winton, 2005: 110)[40]. The aim of the preform stage is to remove between ten and twenty long, thin flakes which run across the face of the biface, at least to the middle (Newcomer, 1971: 88; Whittaker, 1994: 202). Soft hammer

[40] Callahan (1979) notes that a wide variety of holding positions are employed during biface manufacture. Indeed, footage of Callahan replicating a prehistoric knapping episode revealed that he unwittingly utilised 22 different holding positions (1979: 25).

percussion is crucial for this task, because the flakes removed allow the thickness of the biface to be significantly reduced with no concomitant loss of width.

Each removal in the preform stage should serve to either thin or shape the nascent form of the biface. In particular, this stage involves the removal of any ‘bumps’, cortex remnants, or other problem features (such as hinge/step terminations) which might linger from the first stage (Newcomer, 1971: 88; Whittaker, 1994: 202). By the end of the preform stage, the angle of the edges should have been reduced to 40°-60° and the cross section should have a lenticular shape, with a clearly defined tip and base (unless an ovate biface is being produced) and a cutting edge which is reasonably straight and centred (see Figure 7.3, section b) (Newcomer, 1971: 88; Whittaker, 1994: 202).

7.2.3. Finishing/Refinement Stage

The third and final stage of the biface method is the ‘Finishing’ or ‘Refinement’ Stage[41]. The aim of this stage is to impose further thinning, with a minimum loss of width, while also working towards the desired biface shape (Whittaker, 1994: 203). Whittaker suggests this can be achieved by removing ‘large, flat flakes that run past the middle of the face’ (1994: 203). Newcomer, in contrast, suggests removing ‘small thin flakes’ which do not exceed the halfway point of the face of the tool (1971: 90). On either interpretation, the refinement/finishing stage should take between 15 and 30 blows to complete (Winton, 2005: 110), and the knapper should be left with a biface with a flattened cross-section with edge angles of no more than 25°-40° (see Figure 7.3, section c) (Whittaker, 1994: 203). At this stage, the knapper may also choose to switch to a smaller soft hammer tool

[41] Note: Whittaker mentions a fourth stage of biface production which involves further finishing (1994: 203). This relates to the processes involved in producing features such as hafting notches or a serrated edge on a biface, and the use of other stone tool production techniques such as pressure flaking. For the purposes of identifying the information-processing problems of the biface method, the three stages of biface production covered here are assumed to capture the salient areas.

(Newcomer, 1971: 90), which can reduce the risk of the biface shattering under the stress of a blow (a problem which becomes more likely as the biface is progressively thinned, making it more fragile) (Whittaker, 1994: 203).

There is some disagreement regarding the ease with which novices gain proficiency in the various stages of biface manufacture. Winton, for example, notes from his study of skill acquisition in the manufacture of handaxes that the roughing-out stage is the most difficult stage of the biface method, while the final stage may be the easiest for novices to accomplish (2005: 113). Winton argues that this is because the edging/roughing out stages necessitates shaping a raw material with an inconsistent morphology and quality into a form that can be further fashioned into a biface. The later stages of the biface method are, in comparison, more 'standardised' in terms of the knapping procedures involved, because they are applied to a more uniform product: i.e., the unit that results from the roughing-out stage (Winton, 2005: 113). Darmark espouses the contrary view that '…initial edging and primary thinning can be mastered relatively quickly, with proper instruction, while secondary thinning requires more training.' (2010: 2311).

7.3. The Levallois Method

The Levallois method is arguably more complex, and more technically demanding, than the biface method, and represents a definitive example of expert performance (Wynn & Coolidge, 2010: 89). As with the biface method, the Levallois method is typically described in terms of a number of distinct stages (Boëda, 1995; Schlanger, 1996; Van Peer, 1995).

7.3.1. Stage 1: Flake removal from Periphery of Core

The first stage of the Levallois method involves the removal of flakes from the periphery of the core (See Figure 7.4, section a).

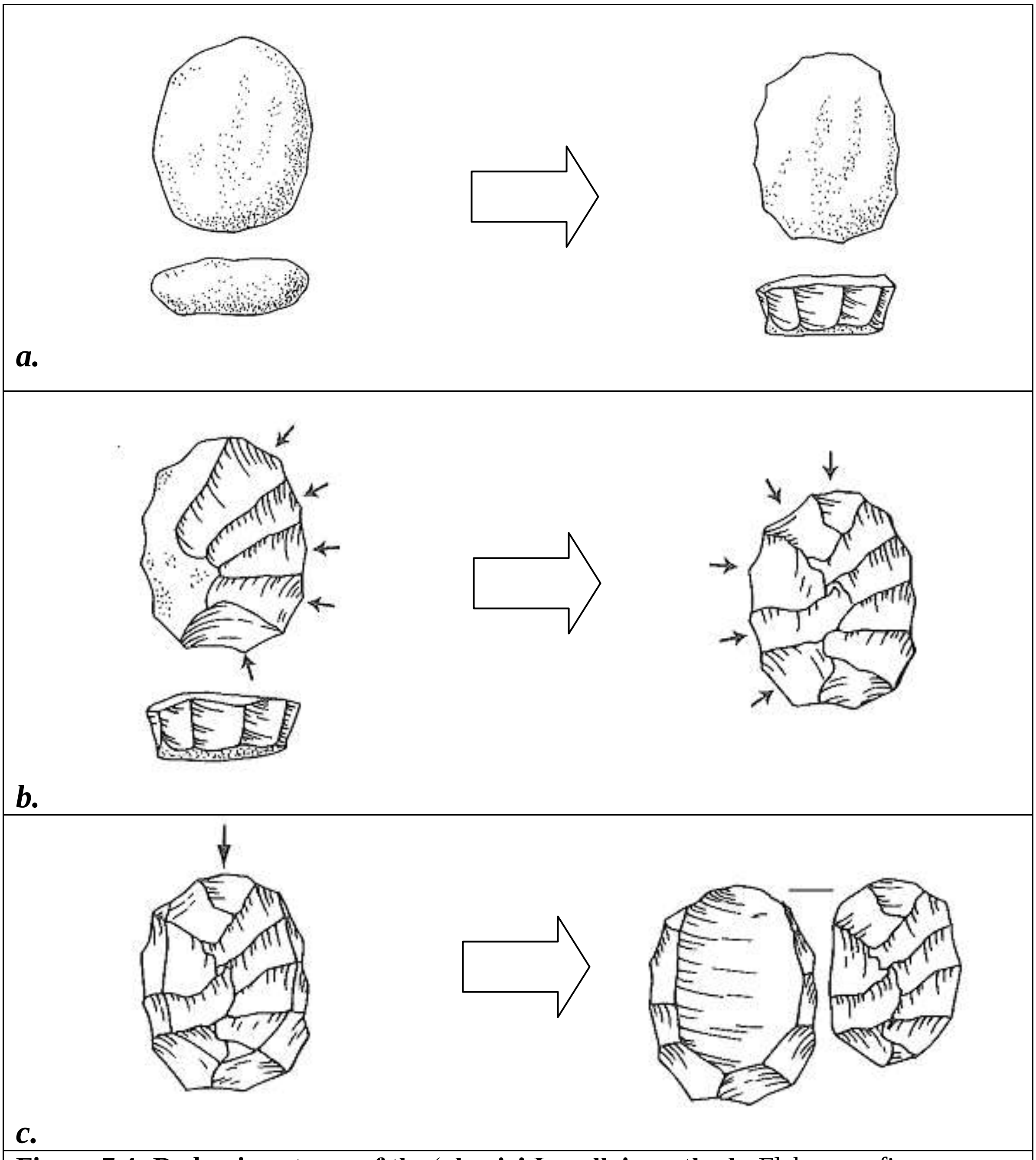


Figure 7.4: Reduction stages of the 'classic' Levallois method. Flakes are first removed from the periphery of an appropriately sized nodule of raw material (a); the flake scars of these initial removals are used to remove further flakes that are struck inwards, across the face of the core (b); a final hammer stone blow removes the final Levallois flake from the core (c) (after Klein, 2009: 487).

Even at this early stage of the methods instantiation, the knapper has specific objectives in terms of the morphological features they are trying to produce on the core.

The Levallois core is commonly described as consisting of two surfaces (the upper and lower surfaces) that intersect on a plane (Boëda, 1995: 46; Chazan, 1997: 724). The specific aim of the peripheral removals is to shape these two distinct, asymmetrical surfaces on the core. Figure 7.5, for example, provides an idealised representation of the two surfaces.

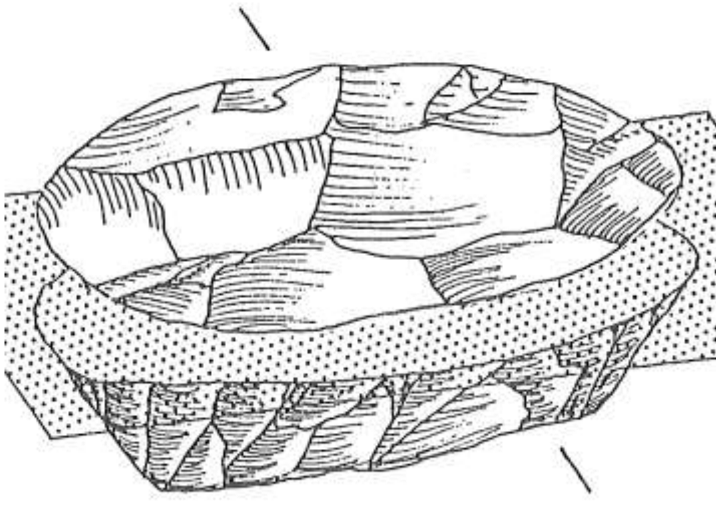


Figure 7.5: The intersecting planes of the Levallois method. Illustration of the two 'intersecting planes' concept utilised in the Levallois method (after Boëda, 1995: 51).

Which part of the core will become the upper surface (the flake production surface) is determined prior to the first flake being removed. In the process of removing flakes from the periphery, the knapper is aiming to produce a 'surface of striking platforms' on the lower surface (Boëda, 1995: 46). These striking platforms are utilised in the second stage.

7.3.2. Stage 2: Inward, Radial Flakes removed

The second stage of the Levallois method involves the removal of a series of radial shaping flakes from the upper surface of the core (see Figure 7.4, section b). This is perhaps the longest and most complex stage of the Levallois method, where a series of twenty or so shaping flakes are typically required (Van Peer, 1995: 2). In removing the shaping flakes the knapper is generally aiming to produce a 'regularly convex' domed upper surface on the core (Pelegrin, 2005: 28). More specifically, however, the knapper aims to produce lateral and distal convexities on the core (see Figure 7.6). The lateral convexities produce a domed appearance when looking face-on, roughly equivalent to the arched hull of an upturned boat. The distal convexity, meanwhile, produces a sloping feature roughly equivalent to the bow of an upturned boat. The distal convexity is situated at the end of the core, opposite the striking platform that will ultimately be used to remove the final Levallois flake (Schlanger, 1996: 235-236).

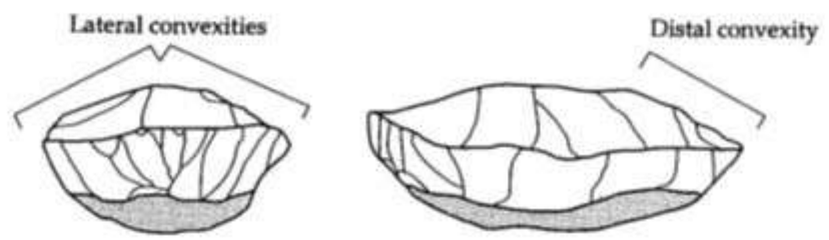


Figure 7.6: The convexities of the Levallois core. When viewing the core head on, the Lateral convexities (left) give the upper surface a domed appearance. When the core is viewed in profile (right) the distal convexity produces a sloping feature on the core. Note that the striking platform is situated directly opposite to the distal convexity (after Wynn & Coolidge, 2010: 91).

It is the careful preparation of the lateral and distal convexities that allows the knapper to 'predetermine' the shape of the flake that is ultimately removed. This is due to the fact that the convexities dictate exactly where the raw material runs out, and therefore where the flake terminates. In removing any extraneous raw material from the core with radial flake removals in this stage, one thereby restricts the possible path of the fracture and ensures that it terminates at the desired point (Schlanger, 1996: 235). As Schlanger notes:

> '…control over the striking surface convexities enables the knapper to determine the plane or 'contour line' along which the fracture wave will travel, the points at which this wave will erupt from the material, and, consequently, the shape, thickness, etc., of the resulting flake.' (1996: 236)

7.3.3. Stage 3: Strike Platform Preparation

The third stage of the Levallois method involves the preparation of the striking platform for the removal of the final Levallois flake (Pelegrin, 2005: 28). The extent of this stage is somewhat contingent on the state of the core once the shaping phase is completed. As Gamble notes, the Levallois method does not necessarily involve modifications to the striking platform (1999: 214). However, where the existing features of the striking platform are unfavourable at the end of the second stage, modification may be both desirable and necessary in order to reduce the risk of errors in the removal of the final flake.

For example, Pelegrin (2005) describes the steps involved in producing an elaborate 'en chapeau de gendarme' platform (see Figure 7.7, sections a-d). Given a core with an adequately shaped upper surface (a), the knapper first removes two flakes either side of the intended strike point, creating a triangle-shaped bump (b). Careful flaking or abrasion with the hammerstone is then employed to remove several smaller flakes in order to produce the facetted surface of the striking platform (c) before the final flake is removed (d).

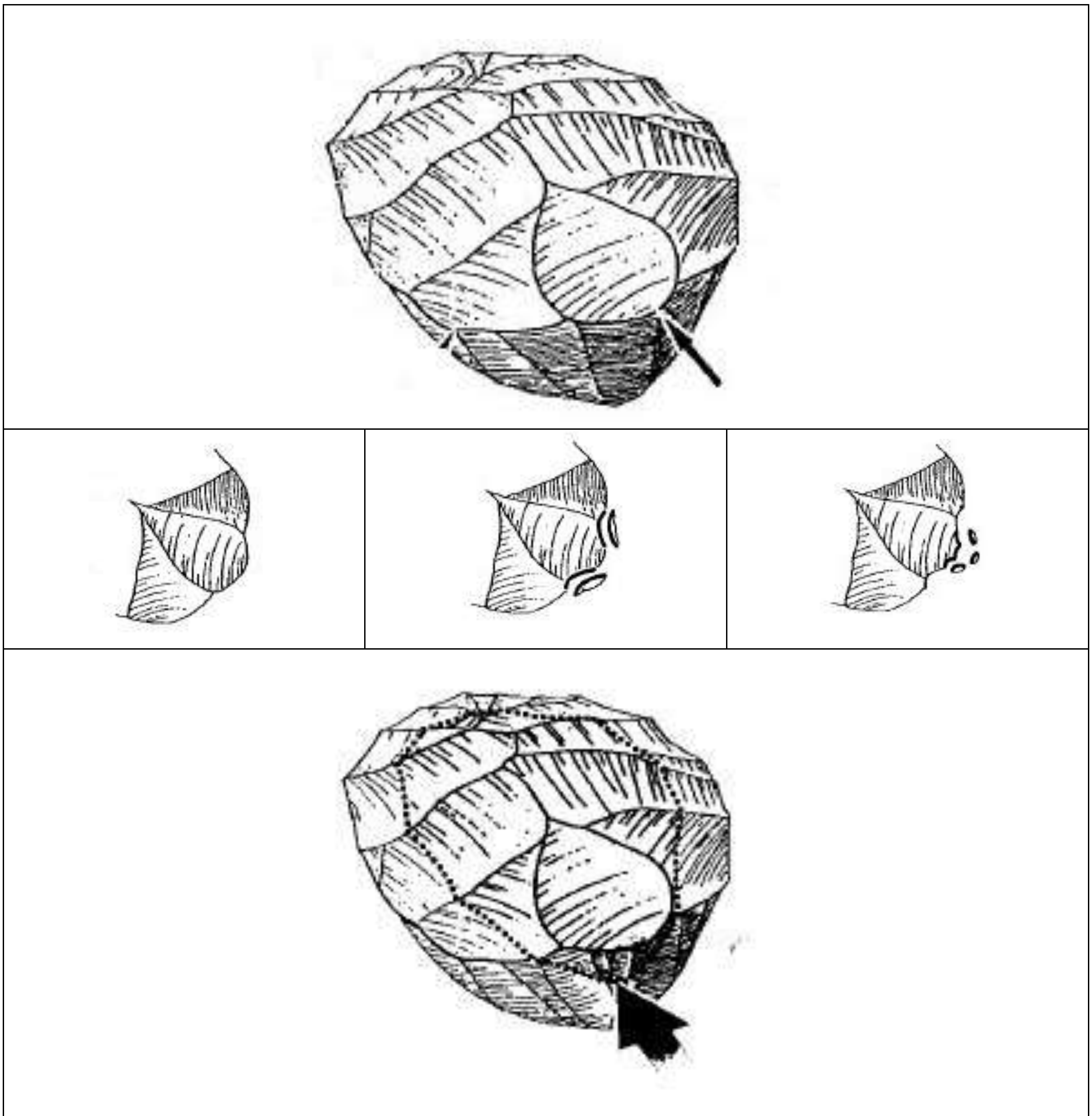


Figure 7.7: The Stages of 'en chapeau de gendarme' platform preparation. *Top:* the initial state of the pre-prepared core prior to any platform modification (the intended striking platform is indicated with an arrow). *Middle row (left to right):* plan view of the stages of the platform modification. Beginning the unprepared platform (left), the knapper first removes two flakes to produce an approximately triangular-shaped boss/hump (middle), before abrading or removing small 'bladelet-flakes' to give the boss/hump a facetted, rounded form (right). *Bottom:* the flake that will be removed from the finished core with its modified platform (adapted from Pelegrin, 2005: 29).

In preparing such striking platforms, the knapper needs to anticipate, to some degree, the effects of the final hammerstone blow on the core. Indeed, platform preparation is most commonly employed to remove undesirable features on the striking platform that might misdirect the force of the final hammerstone blow (Klein, 2009: 487). Ignoring such features can have a detrimental effect on the final result. For instance, in the case of the example above, Pelegrin notes that any asymmetry in the 'bump' produced in the platform preparation could result in the force of the blow being diffused irregularly to one side or the other, resulting in a 'skewed' Levallois flake; setting the striking platform too high or too low on the core, meanwhile, could result in a final flake that is much thicker or thinner than desired (2005: 29).

7.3.4. Stage 4: 'Final' Flake Removal

The final stage of the Levallois method involves the removal of a large flake with a single hammerstone blow (see Figure 7.8).

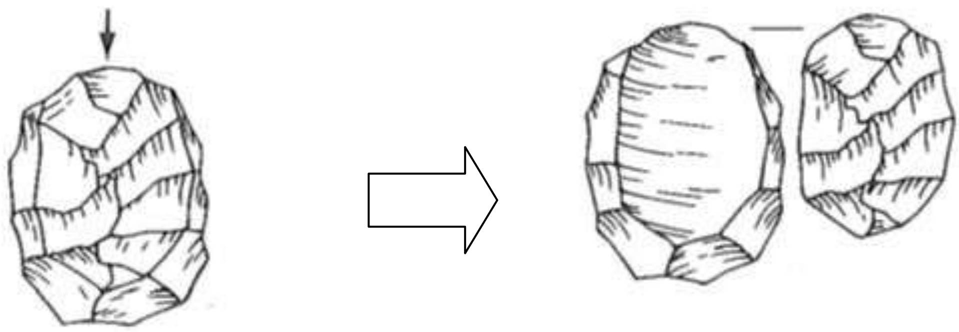


Figure 7.8: A classic final blow in the Levallois method. Illustration of a final hammerstone blow (left) producing a Levallois flake and a Levallois core (right) (adapted from Klein, 2009: 487).

The morphology of this flake is largely predetermined by the morphology of the core following the earlier stages of the Levallois method (Pelegrin, 2005: 28). Schlanger notes that there are three important factors which contribute to the success of the final blow: the platform depth, the blow angle and the alignment of the blow (1996: 236). However, by this stage strict limits have already been imposed on these three factors by earlier core preparation. Figure 7.9, for example, shows a range of platform depths, blow alignments, and blow angles, with successful blows distinguished from unsuccessful blows.

From the beginning of the Levallois method, the knapper would require a clear idea of the alignment of the final blow. This is because they would need to anticipate the path of the fracture wave to fully exploit the lateral and distal convexities prepared in the first and second stages (Schlanger, 1996: 236). Similarly, the depth of the final blow would be determined in stage three, where the striking platform is prepared. Finally, the blow angle will be predetermined in that, given the position of the striking platform, only a blow delivered at a specific angle (within a certain narrow margin of error) will direct the fracture wave through the core along the desired plane (Schlanger, 1996: 236). By the time of the final flake removal, therefore, many of the major choices that will dictate its form have already been made.

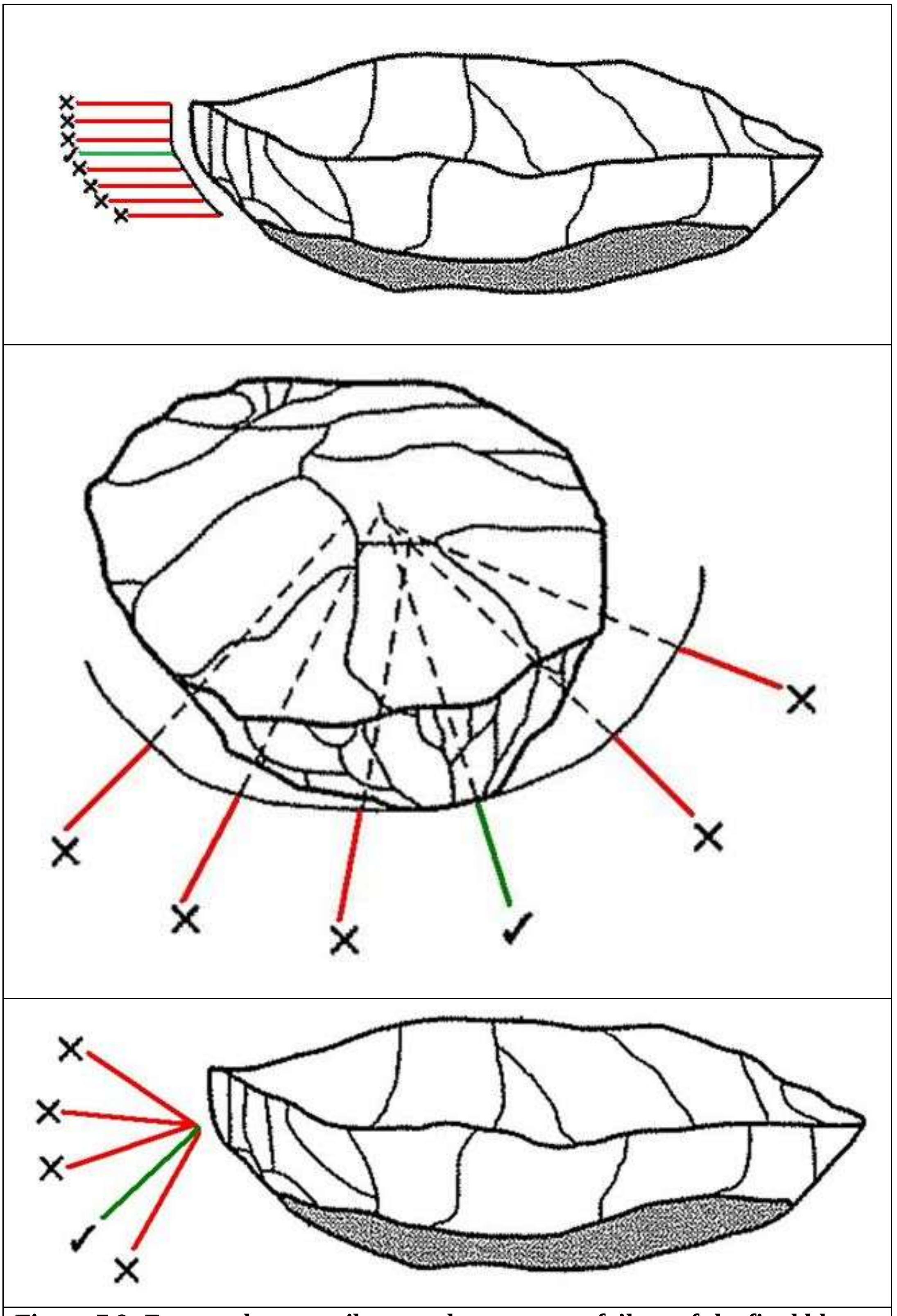


Figure 7.9: Factors that contribute to the success or failure of the final blow in the Levallois method. Illustration of various 'final blow' examples in the Levallois method with the effect of varying platform depths (top), blow alignments (middle), and blow angles (bottom) on the success (green lines) or failure (red lines) of the flake removal (adapted from Schlanger, 1996: 237)

7.4. Intention and Social Context for Stone Tool Production Methods

Prior to any attempt to propose information-processing problems shared between the biface and Levallois methods, one needs to consider the potential problems associated with the evidence presented above. Though the above analyses of the two methods under consideration serves to elucidate the method task domain in important ways, one needs to be wary of simply projecting the intentions and thought processes of modern day knappers into the minds of prehistoric knappers, despite the fact that modern knappers can produce stone tools that are largely the same as archaeological examples.

It is possible, for instance, that various aspects of the method task domain as perceived by modern knappers (e.g., the envisaged stages of manufacture, the rules of thumb that are employed) are modern constructs, and may therefore not have represented a recurrent feature of the task domain over time. For the purposes of performing the present task analysis, therefore, the equifinial nature of the biface and Levallois methods becomes problematic because it invites various different interpretations of the information-processing problems relating to the task domain. This problem is particularly apparent when one considers the issue of intention in stone tool producing behaviours, which remains a contentious area among archaeologists.

For example, it has been proposed, based on a tendency toward standardisation of form in bifacial tools, that the knapping process for biface production was guided by a clear 'mental template' that represented an ideal, preconceived end product (Pelegrin, 2009: 100; Pope, Russel, & Watson, 2006: 46). Pelegrin, for example, cites the repetition of the ‘elongated almond shape’ on hundreds of artefacts recovered from the 700,000 year old site of Isenya in Kenya in support of this view (2009: 100), while Pope *et al* cite examples where knappers go to unusual lengths to preserve the symmetrical form of a biface by making removals that mimic mistakes or flaws present on the opposite face (Pope, et al., 2006: 46). On this view, the biface method is therefore guided by clear intentions, with a preconceived ‘ideal’ form being mentally retained and worked towards through various stages. Ashton and White propose that the practical realisation of this mental construct can be guided by four rules of thumb: namely, bifacial flaking, the creation of a sharp and durable cutting edge, maintenance of broad symmetry, and good prehensile qualities (2003: 119).

Conversely, Davidson argues that the typical biface form is ‘…a frequent outcome of knapping in which acute angles happened to be maintained during the efficient production of flakes for use’ (2010b: 196). On this view, the perceived intent to produce a symmetrical biface form has more to do with the erroneous interpretation of modern day archaeologists than the aims of prehistoric knappers; Davidson ascribes this tendency to a cognitive predilection in modern humans to attribute importance to symmetry (2010a: 222), which in turn bolsters the selective study of such specimens to the detriment of those that do not (Davidson & McGrew, 2005: 808).

The experimental replication studies conducted by Bradley and Sampson, which suggested that the tool morphologies resulting from various different stages of biface production may be misinterpreted as finished artefacts, lends some support to this view (1986). Similarly, Hayden (1989) and Hayden and Villeneuve (2009) question the relevance of symmetrical qualities exhibited by the products of the biface method. They argue that any symmetry discernible in such contexts is equivalent to the symmetry in the tip of a pencil – i.e., it is a byproduct of a process and not an end it itself (Hayden & Villeneuve, 2009: 1167). The biface method is essentially a means of maximising flake production from a given raw material block and symmetry is only important in that it serves to increase the efficiency of such operations (Hayden, 1989: 8; Hayden & Villeneuve, 2009).

In accord with Davidson, Moore argues that bifacial knapping can result from adhering to various 'good tricks' and that the cognitive engagement of the knapper need not extend beyond single flake removals (2011: 710). Far from being the result of the knapper working towards a mental template, the products of the biface method reliably occur as a result of mass redistribution from successive flake removals:

> '…removing a flake redistributes mass non-randomly: high-mass zones are always deflected laterally and distally to the scar's periphery. This non-random process, combined with the 'mindless' application of the flake removal algorithm, could have channelled different core reduction events in similar directions. The result may be morphological clusters of archaeological by-products that appear to have been, by their repetition, deliberately designed according to higher-order intentions.' (Moore, 2011: 710)

> 'Since zones of high mass are inevitably reconfigured - and flake units are inevitably linked together - a hominin stoneworker could have, in theory, reduced a stone without 'thinking ahead' and predicting how removing a flake would reconfigure the mass.' (Moore, 2011: 710)

Finally, Chazan endorses a viewpoint that falls somewhere between the two extremes in attributing a weak form of intent to prehistoric knappers in the form of a 'strategy' which is not rigidly applied (2012: 199). Though the strategy adopted guides the actions of the knapper, the irregular and unpredictable nature of the raw material guarantees that one will never adopt a rigid sequence of actions, and that '…the strategy can only be applied by reacting with flexibility to the constraints imposed by the material' (Chazan, 2012: 199).

Concerning the Levallois method, similar debates have emerged regarding the degree of intention one can discern in its application from archaeological examples and modern reconstructions (Boëda, 1995; Davidson & Noble, 1993; Dibble, 1989; Schlanger, 1996; Van Peer, 1995). Though preconception of the final form of the Levallois flake is often cited as the defining characteristic of the Levallois method, this issue has been the source of some debate. Schlanger, for example, notes that there are two prominent positions regarding predetermination in the Levallois method, dubbed the 'standard' and the 'reactionary' positions (1996).

In the case of the former, the knapper is assumed to possess a 'precise abstract representation' (i.e., a mental image) of the intended final product, together with a systematically planned procedure to meet this end (i.e., the chained sequence of knapping actions that comprises the Levallois method) (Schlanger, 1996: 234). A prominent proponent of this position is Pelegrin, who describes the Levallois as an 'elaborate' method, the complexity of which suggests that prehistoric knappers were 'capable of mentally constructing and selecting short- and long-term sequences of flake removals' to satisfy pre-planned objectives (2005: 28-29). For Pelegrin, the Levallois method:

> '[…] depends upon specifying and then working toward predetermined morphological objectives, and these undoubtedly testify to the existence of operative mental templates […] most flake detachments are not intended as products in themselves, but are carefully adapted via a clear understanding of their effect on the core or on the desired morphology of the perform flake (product).' (2005: 29-30).

In contrast, the proponents of the latter position (see, for example, Davidson & Noble, 1993) reject the notion of extensive planning on the part of the knapper, and instead view the Levallois method as a process that proceeds 'on a flake-by-flake basis' with any apparent standardisation emerging as a by-product of the constraints of the raw material (Schlanger, 1996: 233-234). Levallois flakes are not seen as pre-determined end products on this view, but as flakes struck from the core in order to rejuvenate it; the 'anticipatory' flakes (i.e., those that shape the convexities on the core) are therefore the intended/valued products of the Levallois method (Davidson, 2010a: 223).

To support this view Davidson cites examples of 'final' flakes being preserved with cores, and instances where anticipatory flakes have been removed and used (according to use-wear evidence) more often than the 'final' Levallois flakes (2010b: 197)[42]. Others, such as White and Ashton, note that Davidson's view is not corroborated by evidence of 'missing' final flakes or final flakes being left behind, since various preservation biases may also produce such effects; one is not therefore justified in 'uncritically equating missing elements with human agency rather than excavation or refitting biases' (2003: 602).

As with the biface method, an alternative position somewhere between the two 'standard' and 'reactionary' extremes is feasible for the Levallois method. Dibble, for example, argues that the aim of the Levallois method may have been to extract as many flakes from a given core as possible, which suggests that intention may have played a prominent role in the Levallois method in the absence of any overarching aim to produce a single predetermined flake as an end product (Dibble, 1989, cited in White & Ashton 2003: 603).

[42] However, Schlanger, citing Dibble (1989), notes that it is not a necessary corollary of the 'standard' position that the by-products of Levallois reduction are functionally redundant (1996: 233). Van Peer holds a similar position, where the production of 'reduction elements' via the Levallois method does not mean that the final Levallois flakes were not 'special' compared to other removals (Van Peer, 1995: 4).

Others, such as van Peer, have sought to play down the degree of control the knapper exerted in the knapping process and reframe the 'mental template' concept as more of a 'collective technological knowledge that is transmitted through a learning process' (1995: 5).

For the purposes of the present task analysis, the problem presented by the rival interpretations outlined above is that one can conceivably propose different sets of information-processing problems depending on which interpretation one adopts regarding the degree of intention attributed to the knapper. Given the intractable nature of the archaeological debate this problem is particularly acute, though I would argue that reviewing the issue of intent through the lens of Evolutionary Psychology allows one to circumvent this problem to an extent.

The primary issue here is how one progresses from the task analysis phase to the test design phase (Tooby & Cosmides, 1992: 74-75). Imagine, for example, that one were looking to produce a proxy task for the biface method in order to gather data from test subjects. A decision needs to be made, based on the findings of the task analysis, whether to instruct test subjects to focus on producing an archetypal symmetrical handaxe (Pelegrin, 2005)[43], or removing the maximum number of flakes from the core (Hayden, 1989), or simply removing flakes while attending to various 'good tricks' or rules of thumb (Moore, 2011). Though the task analysis can elucidate the specific problem types a cognitive structure would need to solve to operate efficiently within the task domain, it provides no means of establishing which of the rival interpretations is more feasible.

[43] Geribàs *et al*, for example, tacitly adopt this interpretation when comparing the skills of novice and expert knappers (Geribàs, et al., 2010: 6).

The advantage of adopting the methodology of Evolutionary Psychology, however, is that one can effectively sidestep the requirement of settling on a definitive interpretation of the information-processing problems of the method task domain. Instead, one can acknowledge that rival interpretations of the specific make-up of the information-processing problems exist, before analysing and reanalysing the task from each different perspective, based on different sets of assumptions regarding what is 'going on' inside the head of the knapper. In other words, one can attempt to identify the salient information processing problems for the method task domain according to Pelegrin's interpretation, or Hayden's, or Moore's, before progressing to the process of test design for each[44].

Due to limitations of space, the current task analysis will necessarily be restricted to examining only one of those interpretations. Specifically, the information-processing problems outlined below regarding the method task domain will adopt an interpretation of intent that is largely synonymous with Pelegrin's interpretation. The rationale for adopting this interpretation over others is largely practical in nature: adopting this interpretation allows one to draw extensively on existing data sets that are make the same assumptions regarding the cognitive processes involved (i.e., the accounts of modern knappers, refits from the archaeological data, and examinations of the method *chaîne opératoire* (Boëda, 1995; Callahan, 1979; Schlanger, 1996; Van Peer, 1995; Whittaker, 1994). The descriptions of the various 'rules of thumb' and sequential aims within each stage of the knapping process will provide a useful guide to areas of testing such as learning and instruction. Indeed, similar datasets for the rival interpretations of the method task domain are comparatively sparse.

[44] Indeed, the comparison of results between various testing scenarios has the potential to highlight the conditions in which the human cognitive architecture solves the related information-processing problems most efficiently.

Beyond the practical advantages, however, I find the case presented by those researchers arguing that intention played a prominent role in the application of stone tool production methods to be more compelling than rival interpretations, and I would conjecture that adopting this framework will be most likely to yield interesting results at the testing phase. Schlanger's analysis of Marjorie's core represents a perfect example of this, where a detailed and compelling case is made that the knapper was fully aware of 'the possibilities and consequences of percussion gestures and flake detachment' (Schlanger, 1996: 246).

Though I would maintain that the methodology of Evolutionary Psychology allows researchers to vary their approach to testing based on different sets of assumptions about intent in the application of stone tool production methods, it should be noted that this by no means exhausts the problematic areas concerning 'unknowns' of the task domain. A number of other areas remain highly speculative in terms of how they influence the nature of the information-processing problems that need to be solved during method application.

As Davidson and McGrew state, besides isolated examples of ethnographic study of stone tool production (e.g., Stout, 2002), very little is known of the 'ontogenetic process of acquiring the skills of knapping' (Davidson & McGrew, 2005: 806). Cavalli-Sforza and Feldman, for instance, propose that the social transmission of knowledge can proceed via several different lines (see Figure 7.10), and that the mode of transmission can result in different outcomes (for example, in terms of tool morphology) (Cavalli-Sforza and Feldman 1981, cited in Lycett & Gowlett, 2008: 308)[45]. Note, however, that the mode of

[45] Lycett and Gowlett (2008: 308) refer specifically to the morphology of handaxes, though the same argument arguably holds for any stone tool production method.

social transmission can also imbue different information-processing problems for an individual learner.

Modes of cultural transmission	Vertical or parent-to-child	Horizontal (Contagious)	One-to-many	Many-to-one (Concerted)
• Transmitter	Parents	Unrelated	Teachers/leaders	Elders/peer group
• Transmittee	Offspring	Unrelated	Pupil/disciple	Youth
• Acceptance of innovation	Moderate	Easy	Easy	Extremely low
• Variation between individuals	High	Can be high	Low	Very low
• Variation between groups	High	Can be high	Can be high	Very low
• Rate of cultural evolution	Slow	May be rapid	Very rapid	Extremely slow

Figure 7.10: Four modes of cultural transmission. Illustration of four modes of cultural transmission of knowledge where differing levels of innovation acceptance, individual variation, group variation and cultural evolution occur depending on the mode adopted (after Cavalli-Sforza & Feldman, 1981, cited in Lycett and Gowlett 2008: 307-308).

An individual learner may be faced with the challenge of learning the skills of knapping in varied social contexts (e.g., from parents, a sibling, an older peer, or a village elder) and in varied conditions (e.g., one-to-one, many-to-one, one-to-many). The specific form of the social context that provides the background of the learning environment (as in the scenarios illustrated in Figure 7.3) represents a variable that can subtly alter the nature of the task domain[46]. Though certain aspects of learning, such as apprenticeships, are not wholly invisible archaeologically (Karlin, Bodu, & Pigeot, 1993; Pigeot, 1990), the evidence is understandably scant given the complications with identifying individuals and their respective roles from the archaeological residues of knapping (Pigeot, 1990: 126).

[46] For instance, when completing manual tasks in the company of peers/siblings verses village elders, the latter could be seen as represented a more formal learning environment akin to school lessons, while the former would involve elements that are closer to play and would arguably involve more scope for experimentation.

Indeed, this problem has led Davidson and McGrew to reject the efficacy of testing for examining how stone tool producing behaviours were learned in past environments:

> ‘Experiments are unlikely to provide useful information about learning. One of the crucial factors missing from all experimental stone-knapping is the context of the role of stone tools in the society and hence of the social roles of tool-making, including learning to make them.’(2005: 807)

Again, however, though the unknown aspects of the social context of method learning are certainly problematic, I would maintain that they do not completely negate the prospect of devising appropriate tests. One may adopt a stance similar to the one above and design various tests for various scenarios, relying on best guesses in the first instance (based, as argued above, on interpretations with the largest data set on which to draw). Though limited, some data are available regarding the process of learning stone tool production methods in modern humans. Callahan (Callahan, 1979), for example, provides guidance, based on seven years of testing with approximately 350 students, as to reasonable time frames one would expect to allocate to a novice learning the various stages of biface manufacture, which provides useful boundaries regarding expectations in test design.

More recently, there has been a resurgence of interest, coupled with experimental data gathering, from a group of researchers interested in issues such as comparing the differences in functional mastery of stone knapping and nut cracking (Bril, et al., 2012), how skill contributes to the adaption to task constraints (Bril, et al., 2010), how novice knappers actions differ from expert knappers in a biface manufacture task(Geribàs, et al., 2010), and how stone tool knappers predict the outcomes of knapping actions (Nonaka, et al., 2010). Such studies can serve a point of reference as to how aspects of learning, such as instruction and demonstration, are accounted for in the process of test design.

A further problem for an Evolutionary Psychological approach, and one which on first viewing seems to strongly endorse an interpretation where technical knowledge is wholly retained by cultural means, is that stone tool production methods were learned in many different contexts over time. So though the social contexts of stone tool production method learning are largely unknown, it is safe to speculate that the learning contexts were not homogeneous, and would have varied between prehistoric populations over time.

On closer consideration, however, this highlights both a limitation regarding the extent to which stone tool production methods are explicable in terms of psychological mechanisms, and also a crucial error in Davidson and McGrew's thinking. The error that Davidson and McGrew make here is in assuming that the efficiency of the learning process as a whole is dependent on the minutiae of past social contexts; since the minutiae will forever remain unknowable, they argue, the social context cannot be faithfully replicated (2005: 806-807).

However, from the perspective of Evolutionary Psychology, the whole range of problem types that comprise the social context of method learning are not necessarily relevant. Tooby and Cosmides argue that the only informational cues that are likely to prompt the evolution of dedicated cognitive structures are those that are reliably recurrent (2005: 21-22). The highly variable domain of the social context taken as a whole is therefore unlikely to provide a viable target for a potential psychological mechanism. It does not necessarily follow, however, that cognitive structures could not have evolved to address certain select problem types presented by the various social contexts in which stone tool producing behaviours were utilised.

The prospect of a psychological mechanism that is specific enough to promote behaviours useful to the learning of stone tool production methods, while being general enough to be exposed to the requisite triggers across a broad span of social contexts therefore remains feasible. Indeed, one ready example of such area may be the ability to engage in 'true imitation' (Shipton, Petraglia, & Paddayya, 2009a: 229). For Shipton *et al*, the ability to imitate could contribute to the learning process over vast spans of time (and, therefore, in a variety of social contexts) by guaranteeing a robust form of social transmission, thereby explaining, to some extent, the robust reproduction of stone tool forms visible in the archaeological record (2009a: 229).

Overall, I would therefore argue that the paucity of data regarding the social context of method learning is not an insurmountable obstacle to applying the methodology of Evolutionary Psychology in this area, and I would reject the position that Davidson and McGrew seem to tacitly endorse; namely, that an *a priori* hunch of the futility of experimentation in this area is sufficient to abandon any attempt at test design (2005: 807).

Indeed, by conducting experimental studies into how modern humans learn knapping methods in various contexts one could potentially provide interesting insights into learning in past environments, if only because the human cognitive architecture should be attuned to operating most efficiently in those conditions that were prevalent over time. One can therefore acknowledge that social learning plays a central role in the process of acquiring the skills necessary to competently apply a stone tool production method, while also being open to the notion that certain parts of that learning process may be governed by innate psychological mechanisms.

7.5. The Information-Processing Problems of Stone Tool Production Methods

Given the depictions of the biface and Levallois methods provided above, I propose that the information-processing problems implicated in the process of learning any stone tool production method can be characterised as follows.

To begin with, stone tool production methods can be said to consist of instances of motor action (i.e., single flake removals) that are 'strung together into episodes' (Wynn, 1993a: 392). Since these episodes can be considered non-random, the application of a method further requires the co-ordinated and successive flake removals in accordance with pre-planned objectives or goals, incorporating both short term and long term outcomes (Pelegrin, 2005: 28, 30)[47]. Indeed, both short and long term outcomes are discernible for the various stages described in the above analysis of the two methods under consideration, given the assumptions adopted here regarding the issue of intent.

For example, when considering the biface method, one could posit that a goal-structured approach is evident from the edge blank/roughing-out stage, where hard hammer percussion is utilised to prepare platforms for subsequent soft hammer percussion. In completing this stage, the knapper is not aiming to produce an end product, but a transitional form (i.e., a roughly symmetrical lenticular 'blank') that is somewhere between the initial amorphous raw material and the end product of the biface. The short term goals

[47] Pelegrin notes that a knapping sequence can change as a result of progressing to a different stage/goal (e.g., from pre-shaping to flake production) or as a result of a change of technique (e.g., from hard to soft hammer flaking) (2005: 27-28). Though a change of technique forms a part of the task domain of some methods, there are limitations regarding the extent to which it pervades the task domain of all method types. The Levallois, for instance, is often cited as a technique that requires only hard hammer percussion (though admittedly this percussion type can be employed in different ways, for example in removing flakes, or abrading a platform). For present purposes, therefore, the focus will be on morphological goals relating to the core, therefore excluding any requirement to switch between techniques.

are twofold: firstly, to remove superfluous raw material from the core body and, secondly, to produce viable striking platforms for the subsequent removal of thinning flakes via soft hammer percussion (Winton 2005:113).

The decision of when to switch between techniques is made on the basis of favourable cues on the core that indicate to the knapper that the short term goal has been satisfactorily met, and that the core in amenable to soft hammer percussion. In the absence of such goals, and without attending to cues from the core, the switching between different techniques would be an ambiguous/arbitrary choice, and unlikely to result in a coherent and successful method of producing a biface.

The use of the Levallois method also necessitates such sequential planning incorporating both intermediate and ultimate goals. Again, the first intermediate goal involves the use of hard hammer percussion to produce exploitable striking platforms on the core via the removal of peripheral flakes. The second intermediate stage of the Levallois method involves using hard hammer percussion to exploit these pre-prepared striking platforms to create the lateral and distal convexities on the core. Lastly, where striking platform preparation is used, the knapper employs a third intermediate goal; one which ensures that the force of the final blow is directed as intended to remove the final Levallois flake, after which the process is repeated if feasible. With all these stages, the knapper needs to make a decision as to when each intermediate goal has been achieved, and therefore when to proceed to the next stage of the Levallois method.

Though the ability to set and work towards goals is, on the current interpretation, a fundamental skill in the method task domain, it represents in many ways an end product in terms of knapping behaviours, and one that is only attainable after a degree of expertise has been reached. Research centred on ‘expertise’ in knapping behaviours is an area that is currently in vogue in archaeological research, and various studies have been conducted examining the possible information-processing problems that are solved in the process of attaining expertise (Bril, et al., 2010; Bril, et al., 2012 ; Geribàs, et al., 2010; Nonaka, et al., 2010; Wynn & Coolidge, 2010). From these, and other, studies one can propose a number of other cognitive skills that contribute to success in the method task domain.

The first, and perhaps the most obvious, is the role that memory plays in the retention of information relating to method application. Drawing on the work of psychologists (Ericsson & Delaney, 1999; Ericsson & Kintsch, 1999; Ericsson, Patel, & Kintsch, 2000) Wynn and Coolidge propose that information ‘retrieval structures’ underpin the application of stone tool production methods (2010: 88). The knapper remains largely unaware of these retrieval structures, which are built during numerous practice episodes, until relevant cues arise in the performance of the task at hand (Wynn & Coolidge, 2010: 88).

Of course, this entails that learning a method involves multiple knapping episodes occurring over many hours, allowing ample opportunity for useful ‘rules of thumb’ to be communicated and tested (Callahan, 1979; Moore, 2011), and for risks to be taken, and mistakes made and improved upon (Whittaker, 1994: 206). Indeed, Wynn and Coolidge propose that the very reason novice knappers may find knapping tasks complex is they do not have these retrieval structures embedded in their long term memory, and must instead keep all aspects of the task in their attention (i.e., their working-memory capacity) (2010: 89).

In an earlier paper, Wynn cites a similar concept in explicating three ‘layers’ of tool behaviour: biomechanics, sequence construction and constellations of knowledge/problem solving (Wynn, 1993a). The first of these is most closely linked to learning techniques, while sequence construction involves the individual constructing their own idiosyncratic ‘string of beads’ through repetition and rote memorization where each knapping episode draws on existing memorised sequences and contributes to the ongoing accretion of memorised information through trial, error and revision (Wynn, 1993a: 394, 400).

Finally, following the work of Keller and Keller (1991), Wynn adopts the view that problem solving abilities in tool behaviours are best approached as ‘constellations of knowledge’ (which equate to retrieval structures), where dynamic feedback of the appropriate elements of the task allows the continual adjustment of behaviour (Wynn, 1993a: 397). The role played by memory in the learning of the method task domain is therefore a potentially profitable area for test design, and one that has been subjected to strong selection pressures over time (for example, in improved memory capacity) (Wynn, 1993a: 396; Wynn & Coolidge, 2010: 101).

It is with this final layer of tool making behaviour that the inherently iterative nature of the process also becomes apparent. Though the ability to formulate goal-oriented sequential plans is a crucial facet of the method task domain, this does not mean to say that such planned sequences of action can be applied in a rigid manner, otherwise rote sequence construction alone would suffice for a method’s application. Indeed, the application of a method is a dynamic process, and one that needs to be adaptable to the contingencies of a raw material which does not always fracture as the knapper intends.

How closely one can adhere to any pre-determined goals depends on how closely one's constellations of knowledge coincide with the actual fracturing of the raw material. Where errors occur due to a mistake on the part of the knapper, an imperfection in the raw material used, or a combination of both these factors, the application of a given method can be compromised to a greater or lesser extent. As a result, any planned flake removal sequence may require reassessment and result in further planning which takes the new state of the core into account.

The constant monitoring of the core, and the adjusting of one's knapping sequence accordingly, are therefore integral aspects of any stone tool production method (Mithen, 1996: 120). Contingency is therefore often necessary; here is Schlanger on how *conceptual* sequences and *actual* sequences interplay with each other in the application of the Levallois method:

> 'The crucial point […] is that – as raw material is never standard in shape or composition, and striking actions cannot be undertaken with perfection – it cannot remain an immutable sequence: 'input' and 'output' interact with each other, contingency is all too often necessary. If the blueprint is blurred, and the artefact's template is somehow fluid in its material becoming, so is, in a way, its mental counterpart. In its co-incidentally predictable and random responses, the transformed material creates new problems and generates ever-changing configurations to be perceived and knowledgeably addressed.' (1994: 148)

As alluded to in the quote above, a further important cognitive skill associated with forming constellations of knowledge is the ability to conceptualise (i.e., 'think through') a sequence of flake removals (Pelegrin, 2005: 29). This could be as simple as envisaging (rather than enacting) how a sequential series of flake removals might transform the core from one state to another. This skill, termed ‘reversibility’ (Wynn, 1993a: 400), has obvious advantages. Since stone tool production is in essence a reductive process, an erroneous flake removal cannot be physically reset and reattempted (Darmark, 2010: 2311). The ability to practice a method mentally represents a low cost, low risk means to ‘test’ possible action sequences prior to committing to one course of action or another. Arguably, individuals who were capable of such mental experiments would not only be better knappers, but they would be much less wasteful in the use of raw material.

However, the degree of utility attributable to the ability to think one’s way through a series of flake removals is dependent on the extent to which ones imagined flake removals correspond to what is feasible in the real world – i.e., the knapper needs to know what can and cannot be achieved given both the properties of the raw material in general and the state of the raw material at any particular juncture. The acquisition of such skills is an essential step to mastering the application of stone tool production methods. Experiments by Winton, for example, which compared expert and novice use of the biface method noted that novices (but not experts) typically make the mistake of attempting ‘radical’ morphological alterations quite late in the procedure (2005: 113-114). Finally, cognitive abilities such as the ability to engage in planning in three dimensions simultaneously (Alexandra Sumner, 2011: 2311; Wynn, 2002: 397) and the ability to perform mental rotations of 3-dimensional objects (Shepard & Metzler, 1971), may also have contributed to success when tackling this facet of the method task domain.

7.6. Establishing Specificity to the Task Domain

As with the previous chapter that dealt with stone tool production techniques, performing a task analysis of stone tool production methods requires establishing, as far as is feasible, that the information-processing problems under consideration are not associated with other adaptive behaviours (or, in other words, that the problem types represent a task domain that is truly distinct) (Tooby & Cosmides, 2005: 28). If one is seeking to identify a genuine link between the proposed task domain and any cognitive biases detected during testing, then one needs to consider whether alternative explanations (such as the prospect of method-related behaviours utilising pre-existing cognitive structures) do not provide equally viable explanations.

This step is complicated, to an extent, by the prior-stated overall aim of the current task analysis, which is to identify information-processing problems that are shared between the two methods under examination. This forces one to walk a tightrope between generality on one hand (i.e., information-processing problems that are general enough to be shared between all method types) and specificity on the other (i.e., information-processing problems that are general enough to be shared between all method types, but not to the extent that they are implicated in numerous task domains beyond that of stone tool methods).

Prima facie, the scope of the problem-types proposed above falls into the latter category. In addition to executing a stone tool production method, the ability to, for example, build and store retrieval structures in memory represents a cognitive skill that is beneficial for solving problems in a wide variety of domains. In one important respect, however, an argument can be made that the cognitive abilities listed above remain specific when utilised within the domain of stone tool production.

Given the characterisations of the biface and Levallois method above, it is clear that an intimate knowledge of the fracture properties of the raw material and an acute awareness of how ones knapping gestures will affect that raw material is a prerequisite for applying stone tool production methods. The utilisation of a stone tool production method relies in the first instance on proficiency in a technique, and by extensions the application of a method occurs within a task domain that is similarly bounded by the fracture properties of brittle solids (Moore, 2011: 702-703). As a consequence, I would argue that one encounters the same degree of specificity in the method task domain as in the task domain described in Chapter 6 for stone tool production techniques.

So though an ability to build and store retrieval structures in memory can be beneficial in a broad sense, what counts as efficient building/storing of retrieval structures may be contingent on the specific details of the task domain. One can therefore posit that despite the general nature of the problem-types proposed above, when solved in the area of stone tool production it remains feasible that discrete cognitive structures may have evolved to facilitate the learning process. A general 'retrieval structure building' ability may, given enough time and adequate selection pressures, cause selection for cognitive structures that can more efficiently solve 'retrieval structure building'-type problems within the narrow task domain of stone tool production[48]. Of course, it also remains feasible that the

[48] Note that Wynn adopts the view that selection pressures may have prompted the evolution of memory capacity over time, (Wynn, 1993a: 396; Wynn & Coolidge, 2010: 101) while simultaneously rejecting the notion that any aspect of the workings of memory may be specifically attuned to solving the tasks inherent in stone tool production. Instead, he argues that cultural, non-innate forces (referred to as a 'Technology Acquisition System) provides adequate explanation for the acquisition of technological skill (Wynn, 1993a: 402)

converse case may in fact be true: that stone tool production method learning may be accounted for by appeals to a general ability to, say, build and store retrieval structures in memory that evolved for different reasons that is co-opted during stone tool method behaviours. The challenge is therefore to design tests that will discriminate between these two hypotheses, which is an issue that will be considered in subsequent chapters.

7.7. Conclusion

In conclusion, the aim of this chapter was to perform a task analysis for two stone tool production methods (the biface and Levallois) in order to identify the information-processing problems that are salient to application of both. Initially, I therefore provided characterisations of each method drawing on accounts of both modern knappers and archaeological reconstructions.

Two potential obstacles to the aim of identifying the shared information-processing problems of the methods under consideration were highlighted. Firstly, I discussed the issue of intention, noting that there are differences regarding the degree of intent some researchers are willing to attribute to the knapper based on the evidence available. Secondly, I discussed the ‘unknowns’ of the social context within which stone tool production methods were learned in the past. The challenge presented by these problems is that different information-processing problems could be proposed depending on the degree of intent involved in method application and the specifics of social learning context. However, I further argued that the methodology of Evolutionary Psychology allows for the testing of multiple task domain scenarios and that this issue can be sidestepped to an extent.

In outlining the information-processing problems of the method task domain, I contended that cognitive abilities that facilitate the attainment of expertise are the most relevant, where expertise is indicated by an ability to impose sequences of multiple flake removals to a core in accordance with both long-term and short-term goals. I argue that a psychological mechanism to facilitate the embedding of retrieval structures/constellations of knowledge and the ability to ‘think through’ removal sequences would be advantageous to any individual learning a stone tool production method.

Finally, in considering the issue of specificity, I argued that though the ability to build and store retrieval structures in memory would be beneficial to a wide variety of tasks, the specificity of the method task domain is maintained due to their utilisation in association with a stone tool production technique, which incorporates unique problem types as described in Chapter 6.

Chapter 8: Testing for Psychological Mechanisms Relating to Stone Tool Production Techniques and Methods

> '[Evolutionary psychologists] see the psychological mechanisms that make up the human mind as evolved adaptations. Further, they are convinced that these adaptations are more likely to produce adaptive effects in environments similar to ancestral ones. In other words, the more similar the present environment is to the ancestral one, the more likely the adaptation is to confer the reproductive advantage that led to its evolution. On the other hand, adaptations are less likely to confer an adaptive advantage in novel environments.' (Irons, 1998: 194)

8.1. Introduction

The aim of this chapter is to propose experimental test designs to examine whether psychological mechanisms dedicated to solving the information processing problems of the respective task domains of stone tool production techniques and methods are present in the human cognitive architecture. To achieve this Tooby and Cosmides suggest that a wide range of methods can be employed, most notably, from '...cognitive, social, and developmental psychology, cognitive neuroscience/neuropsychology, experimental economics, cross-cultural studies—whatever methods are most appropriate for illuminating programs with the hypothesized properties' (2005: 28).

To this end, I will first describe the process of test design in psychology, focusing particularly on the identification of the independent and dependent variables, and how one can manipulate these variables in an experimental setting to examine whether a causal relationship exists between them. I will also consider the steps required to rule out other causal explanations for any observed effect evident from testing.

I will then expand on this general framework to outline the additional commitments made by Evolutionary Psychologists during the test design process. In particular, I will highlight the importance of generating hypotheses with reference to ancestral problem types within the *Homo* line, the focus on testing for the psychological mechanisms that evolved to solve those problems, and the contemplation of evolutionarily significant background conditions during the test design process.

With reference to the general framework of test design in psychology, and the specific framework proposed by Evolutionary Psychology, I argue that test design in the area of stone tool production should focus on the most adaptively relevant facet for the task domain: namely, learning to exploit the conchoidal fracture properties of stone. I propose an 'in principle' test design to examine whether the human cognitive architecture contains psychological mechanisms dedicated to facilitating the processes of learning to exploit conchoidal fracture.

The aim of the test design is to examine the hypothesis that, all other things being equal, test subjects will learn to solve the information-processing problems of the technique/method task domains most efficiently when the raw material employed exhibits fracture properties consistent with those reliably encountered by our ancestors in past environments. I further argue that the introduction of a hypothetical raw material type with fracture properties that deviate from those displayed by any naturally occurring stone would provide a means to test and compare the efficiency of learning between two groups of test subjects.

Finally, I consider whether it is feasible to carry out the 'in principle' test design in practice. For both stone tool production techniques and methods, I outline possible approaches to testing the ability of subjects to learn stone tool production related skills in two sets of conditions: first, where the raw material exhibits fracture properties similar to naturally occurring stone and, secondly, where the fracture properties of the raw material deviate in some respect from naturally occurring stone.

8.2. Test Design in Psychology

In general, approaches to test design in psychology can be broadly delineated into two distinct methods: the observational/correlational method and the experimental method (Field & Hole, 2006: 3). The former consists of observing and recording aspects of the real world without any interference, while the latter involves devising tests in which some aspect of the environment is manipulated in order to observe its effect (Field & Hole, 2006: 3). The specific method adopted here will be experimental because the main aim of the test design will be to manipulate the variables inherent in the task domain of stone tool production in order to observe an effect (or, indeed, a lack thereof).

As with other areas of science, psychologists adopting the experimental method propose theories from which hypotheses are generated and tested (Field & Hole, 2006: 15). The hypotheses generated typically concern a posited causal relationship between one or more variables (Field & Hole, 2006: 15); tests are designed, therefore, in order to gather data to corroborate whatever cause and effect relationship is purported to exist between the variables.

In any experimental test the variables that are to be targeted in the test design need to be clearly characterised. Indeed, the first important principle of experimental research in psychology concerns the isolation of the causal variable:

> '[…] the only way to infer causality is through comparison of two controlled situations: one in which the cause is present and one in which the cause is absent. These situations should be identical in all senses except the presence of cause [...]' (Field & Hole, 2006: 15)

Variables can be either independent or dependent; the former is the variable that is manipulated while the latter is the variable that is measured (Harris, 2008: 129). As Field and Hole state:

> 'The variable that is manipulated is called the *independent variable* (because its value is independent of the other variables in the experiment, it instead depends on the experimenter) whereas the outcome variable, the one that is not manipulated by the experimenter, is called the *dependent variable* (because its value depends on the other variables in the experiment).' (2006: 21 - original emphasis)

Once the independent and dependent variables are identified, the process of test design involves devising scenarios where the proposed causal (independent) variable is manipulated (Harris, 2008: 133). The manipulation of variables can occur on various ‘levels’, the simplest of which consists of two levels, where the proposed causal variable is either present or absent (Field & Hole, 2006: 21; Harris, 2008: 128).

Field and Hole, for example, illustrate this point with a hypothetical example examining whether the radiation emitted by mobile phones causes brain tumours (2006: 21). A simple ‘two-level’ approach would consist of a test where the causal variable (i.e., exposure to mobile phone radiation) is either present or absent for two sets of test subjects in order to examine the incidence of brain tumours (the outcome variable). However, it is also feasible to introduce various other levels of exposure of the causal variable; for example, test subjects could be exposed to mobile phone radiation for one hour a month, one hour a week, one hour a day, and so forth (Field & Hole, 2006: 21).

The second important principle of experimental research in psychology consists of ruling out other causal explanations for any observed effect in the outcome variable (Field & Hole, 2006: 21). This can be achieved by taking steps to minimise the effect of random factors that may influence the outcome of the experiment by either holding them constant or randomising parts of the study (Field & Hole, 2006: 21, 24). For example, holding other factors constant in the mobile phone radiation test may require taking such steps as ensuring the same mobile phones were used (because radiation levels may vary with different types of phone) and ensuring no systematic bias was introduced due to the initial state of the test subjects’ brains (for example, one would exclude anyone subject with a previous history of brain tumours) (Field & Hole, 2006: 21).

Similarly, the random allocation of subjects to test groups would be required in the hypothetical mobile phone radiation test to avoid introducing potential bias (if some of the test subjects have a history of head injuries, for example, it would be necessary to distribute them randomly between the test subject groups) (Field & Hole, 2006: 24). Finally, the veracity of the inferences one can draw from the results of a given test depend on the appropriate statistical analysis of results in order to establish that any differences observed between experimental groups is of a sufficient magnitude that the influence of chance can be discounted (Field & Hole, 2006: 25). Ideally, this would include replication of the test/results: '…our confidence in a given scientific statement will increase if a given set of results can be replicated many times (and by different researchers)' (Field & Hole, 2006: 26).

8.3. Test Design from the Perspective of Evolutionary Psychology

Given the general outline to test design is psychology provided above, there are a number of additional points that need to be kept in mind regarding test design when viewed through the lens of Evolutionary Psychology. It is first worth noting, however, that test design in Evolutionary Psychology concurs for the most part with the outline presented above. Consider, for example, Cosmides and Tooby research into the detection of cheaters in social exchange contexts (Cosmides, 1989; Cosmides & Tooby, 1989). In these studies, the researchers identified an effect (i.e., the ability to detect cheaters) and a cause (i.e., the social exchange context) and set out to conduct experiments in such a way as to contrast two otherwise identical situations where the cause is present or absent. To achieve this they utilised a Wason selection task, as illustrated in Figure 8.1, to present subjects with a task based on the conditional rule: *If P then Q* (Tooby & Cosmides, 1997: online). In testing, the content of the selection task was manipulated to include or exclude information relating to a social exchange context (the cause) while the underlying logic of the problem remained unchanged (further discussion of this research is included below).

Instructions

Part of your new job for the City of Cambridge is to study the demographics of transportation. You read a previously done report on the habits of Cambridge residents that says: **"If a person goes into Boston, then that person takes the subway."**

The cards below have information about four Cambridge residents. Each card represents one person. One side of a card tells where a person went, and the other side of the card tells how that person got there. Indicate only those card(s) you definitely need to turn over **to see if any of these people violate this rule.**

Boston	Arlington	subway	cab

Figure 8.1: A Wason selection task designed to test subjects' ability to identify violations of a conditional rule of the form If P then Q. In terms of the inherent logic of the task, test subjects should only turn over the *Boston* card (because the rule would be broken if this person didn't take the subway) and the *cab* card (because the rule would be broken if the person taking the cab went to Boston). Tooby and Cosmides observe that fewer than 25% of subjects spontaneously make the correct response. In contrast, 65-80% of subjects give the correct answer when the content of the task concerns violations of social contracts (after Tooby & Cosmides, 1997).

Though the methodology of Evolutionary Psychology is largely in agreement with the general approach to test design in psychology, the hypotheses proposed by its proponents focus explicitly on specific psychological mechanisms; i.e., structures within the human cognitive architecture that have been functionally organised by natural selection to address the myriad adaptive problems encountered in past environments (Buss, 1999: 42-43; Tooby & Cosmides, 1992: 66, 2005: 21-22). A resulting caveat is that research should initially focus on identifying a viable adaptive target (Tooby & Cosmides, 1992: 73).

Indeed, one of the defining characteristics of Evolutionary Psychology is the generation of hypotheses that focus on the adaptive problems faced by our ancestors, while research adopting its methodology seeks to elucidate the properties of the purported solutions to those problems (i.e., psychological mechanisms) (Buss 1999: 39). Potential adaptive targets are deemed viable only if they meet two conditions: firstly, the successful solution of the adaptive problem (i.e., the solution of the associated information-processing problems) must proffers an advantage (however small) in terms of survival or reproduction and, secondly, they must be recurrent (i.e., the task domain of the adaptive problem under consideration should not vary significantly over time, and should be deep-seated enough in the evolutionary history of our species to allow adequate time for natural selection to occur) (Tooby & Cosmides, 2005: 21-22). Chapters 4 and 6 of this thesis addressed these issues for stone tool production techniques and methods respectively, arguing that both represent viable adaptive targets for the evolution of a dedicated psychological mechanism.

A further consideration that distinguishes Evolutionary Psychology from psychology in general concerns the background conditions that are taken into account during test design. For Evolutionary Psychologists, this should include '...a description of the recurrent structure of the ancestral world that is relevant to the adaptive problem' (Tooby & Cosmides, 1992: 73). Evolutionary psychologists argue that for every adaptation there is a corresponding environment of evolutionary adaptedness (EEA), which 'refers jointly to the problems hunter-gatherers had to solve and the conditions under which they solved them (including their developmental environment)' (Tooby & Cosmides, 2005: 22). It is posited that any given psychological mechanism will be attuned to those background conditions that were prevalent in its EEA, and the efficacy of the mechanism is contingent on the presence of those conditions (Tooby & Cosmides, 2005: 22). Therefore a given psychological mechanism will function well in conditions that closely resemble its EEA, while in conditions that diverge from its EEA it will function comparatively worse.

Returning to the example cited above regarding Tooby and Cosmides' studies into the detection of cheaters in social exchange contexts, it is clear that their research incorporates the facets of the methodology of Evolutionary Psychology mentioned above, while simultaneously adhering to the general approach to test design in psychology. For example, the research targeted a long-enduring adaptive problem in the *Homo* line to formulate hypotheses in the first instance, and to subsequently design tests to see: '…what content-manipulations switch on or off high performance' (Tooby & Cosmides, 1997: online). The test design focuses on setting up two contrasting scenarios where different outcomes would be expected if the human cognitive architecture were domain-general or domain-specific in terms of its operation. In other words, the researchers sought to gather data to challenge the hypothesis that the architecture of the human mind operates via general-purpose mechanisms (which, they argue, is an unlikely outcome of a cognitive architecture shaped by natural selection) and corroborate the rival hypothesis that the human cognitive architecture operates via many domain-specific mechanisms.

> 'From an evolutionary perspective, the human cognitive architecture is far more likely to resemble a confederation of hundreds or thousands of functionally dedicated computers, designed to solve problems endemic to the Pleistocene, than it is to resemble a single general purpose computer equipped with a small number of domain-general procedures…' (Tooby & Cosmides, 2006: 183)

The results obtained, they argue, support this interpretation for the subject area they targeted, where fewer than 25% of subjects successfully identified the logical violations of conditional rules in Figure 8.1 (i.e., social context absent), compared to 65-80% of subjects providing the correct answer when the content of the task was altered to describe violations of social contracts (i.e., social context present) (Tooby & Cosmides, 1997: online). From this discrepancy, they concluded that humans are equipped with 'cognitive adaptations specialized for detecting cheaters in situations of social exchange' (Tooby & Cosmides, 1997: online).

8.4. Testing for Psychological Mechanisms Relating to Stone Tool Production *In Principle*

Given the above précis of the process of test design in psychology generally, and in Evolutionary Psychology specifically, we are now in a position to formulate an 'in principle' test to examine whether psychological mechanisms dedicated to solving the information-processing problems of stone tool production are present in the human cognitive architecture.

I propose that the cause and effect relationship that will provide the focus of the current test design is between the conchoidal fracture properties of the raw material used in the task (the proposed cause, or independent variable) and the efficiency of learning of stone tool producing behaviours (the effect, or dependent variable). The test design should therefore focus on gathering data to examine whether a causal relationship exists between these two variables.

For Field and Hole, inferring causality is best achieved via two controlled test situations: one in which the cause is present, and one in which the cause is absent (2006: 15).

Concerning stone tool production, however, it is clearly not feasible to remove the cause completely, because a physical substrate of some kind is required on which to enact percussive blows. Instead, one needs to devise test situations where the cause is present in a form consistent with that encountered by our ancestors in the EEA and compare it with situations where the cause varies in some important respect from EEA conditions (this is equivalent to the different levels of manipulation of the causal variable mentioned above) (Field & Hole, 2006: 21).

As I have argued in previous chapters, the information-processing problems of stone tool production consist of a set of technical skills that need to be mastered in order to exploit the conchoidal fracture phenomenon. Indeed, the property of conchoidal fracture, inherent in certain naturally occurring stone types, represents an invariable, recurrent feature of the EEA of stone tool production. The conchoidal fracture phenomenon can be viewed as a significant background condition regarding the EEA of stone tool production.

One could therefore posit that, in principle, any variation in the conchoidal fracture properties of stone would affect the efficiency of any psychological mechanism dedicated to solving the information-processing problems of the task domain. Consider, for example, a hypothetical stone type called ‘slint’. Slint looks and feels exactly like flint and produces flakes of the same type as flint. However, slint does not fracture in the same way as flint, or any other naturally occurring stone, because the conchoidal fracture properties that slint displays differ from those that would typically have been encountered in the EEA of stone tool production. The process of removing flakes from a slint core still requires an ability to produce precise blows on a platform while taking into account factors of core morphology, blow strength, and the angle of the blow. However, the way in which these variables need to be attended to in removing a flake from a slint core consistently differs in certain respects when compared to flint.

For example, removing a flake successfully from a slint core might involve utilising more acute blow angles than those typically employed in removing flakes from a flint core. The ideal blow strength may also differ, with stronger or lighter blows being required to engender a flake removal from slint cores. Similarly, what counts as an ideal platform depth may differ, so a platform depth which would be unworkable for removing a flake from a flint core might, in fact, be optimal for removing a flake of slint. In this sense, an individual learning to knap using slint will encounter a task domain that is different from an individual learning with flint, to the extent that a learning strategy that is successful for one type of raw material will be comparatively less efficient when attempted on the other.

8.4.1. The Slint/Flint Test

The utility of slint, the hypothetical stone-type outlined above, is that it allows one to test between two competing hypotheses for how the skills of stone tool production are acquired. One such explanation suggests that our brains have a general capacity to learn new skills, which is bolstered significantly by learning within a social setting via apprenticeship (see, for example, Wynn, 1993a: 402). The second suggests that our brains are equipped with specialised psychological mechanisms that have evolved to solve problem types within specific domains (such as stone tool production) and that such programs facilitate the process of skill acquisition. Unfortunately, both explanations predict the same outcome regarding the acquisition of stone tool producing skills: *viz.* a novice will, with adequate practice and instruction, learn the skills required. Arguably, however, the same outcome is predicted by both explanations *only if* the raw material employed displays conchoidal fracture properties synonymous with those encountered in the EEA.

Consider the slint/flint test, which compares how well test subjects learn stone tool production skills when using flint verses slint. Let us suppose that we have two different groups of test subject available. The first group all have brains equipped with specialised psychological mechanisms that facilitate the acquisition of stone tool production skills, and these mechanisms are attuned to cope with the specific fracture properties of flint. The second group all have brains equipped with a general learning capacity to learn without specialisation. When comparing the two types of subject one can predict, *ceteris paribus*, two very different outcomes in terms of how easily they will learn stone tool production skills when utilising the two different types of raw material.

For the group of test subjects with a general-purpose learning ability, one can predict that the differences in raw material will have no affect on the learning process, and so the requisite skills will be acquired with the same efficacy regardless of whether the raw material is flint or slint. In contrast, the group of test subjects with specialised psychological mechanisms will learn more efficiently when utilising the raw material that the aforementioned mechanisms evolved to accommodate (i.e., flint), and less efficiently for slint, which necessitates the solution of information-processing problems that deviate from those encountered in the EEA of stone tool production.

Relating this hypothetical example to the current task of test design, it becomes apparent that the effect (the outcome variable) that one is aiming to measure is therefore the efficiency with which stone tool production skills (for either technique or method) are acquired. Similarly, the fracture properties of the raw material used represent the proposed cause (the independent variable), and these properties can vary from a faithful replication (i.e., where the cause is robustly present) to conditions where the cause is present in a form that varies from those typically found in the EEA to a greater or lesser extent. The main contention is that since the reliably recurring fracture properties of stone present a constant background condition for stone tool production behaviours, the imposed variation of these conditions will impede (however subtly) the efficiency of any psychological mechanism dedicated to facilitating the learning process. As Barrett argues, 'dimensions of variation ' that were either absent in the EEA or which had no fitness consequences attached 'are often invisible to the mechanism' (Barrett, 2009: 103)

In effect, this turns a prevailing assumption regarding skill acquisition in stone tool production on its head. To date, researchers have tended to assume that the learning process within the stone tool production task domain is inefficient because novices experience significant difficulties in attaining the necessary skills (Milne, 2005: 336). By adopting the perspective of Evolutionary Psychology, in contrast, one can instead question whether the learning process would become *even more inefficient* when a significant, reliably recurring background condition of the task domain is altered. In other words, it may be the case that the conventional modes of learning stone tool production actually represent the most efficient possible solution to the information-processing problems presented by the task domain and, furthermore, that these ostensibly cumbersome conventional modes of learning will become even more encumbered when an important background condition of the task domain is altered.

Indeed, it is notable that though research into skill acquisition in the area of stone tool production is currently enjoying a resurgence (Bril, et al., 2009; Bril, et al., 2010; Bril, et al., 2012 ; Geribàs, et al., 2010; Nonaka, et al., 2010), no study to date has considered varying the fracture properties of the raw material employed. Instead, the exclusive focus is on designing tests that incorporate either a naturally occurring stone suitable for knapping (e.g., flint or chert) (Nonaka, et al., 2010; Winton, 2005), or some other faithful analogue (e.g., a conchoidally fracturing material such as brick) (Geribàs, et al., 2010). I would argue that a potentially informative approach to examining skill acquisition in stone tool producing behaviours may have been overlooked as a result.

Of course, the above discussion is largely academic unless the slint/flint test can be carried out in practice. To achieve this, however, one first needs to circumvent an obvious obstacle: namely, that slint remains hypothetical. Below, I will argue that this may be feasible by producing a physical approximation of the slint/flint test which retains the relevant ‘adaptive triggers’. As argued previously, separate psychological mechanisms dedicated to solving the problem-types encountered while learning stone tool production techniques and methods may be present in the human psychological architecture because, first, the respective task domains present distinct information processing problems and, secondly, because the archaeological evidence suggests that the information-processing problems of one aspect of stone tool production (i.e., that of technique) significantly predates the emergence of the other (i.e., that of method). Different types of test are therefore conceivable when examining technique and method, which will be discussed in turn below.

8.5. Testing for Psychological Mechanisms Relating to Technique In Practice

For the following, primarily for reasons of brevity, I will focus specifically on characterising a practical outline of the hard hammer percussion task domain, though specific issues associated with test design for soft hammer percussion will be considered at the end of this section.

A practical equivalent of the slint/flint test could conceivably employ a ‘proxy core’ which would be made from a material that will not fracture (such as a hard plastic or rubber). The core would be moulded in such a way as to present various exterior platform angles to the test subject, ideally drawing on a typical lithic core as an example. Test subjects would be taught to ‘knap’ on the proxy core by an expert knapper, who would instruct them in the use of the hard hammer percussion technique.

In order to collect data relating to the performance of the test subjects, motion capture technology would be used to record the blow placement, blow angle and velocity of each attempted blow; similar technology has already been employed to study the biomechanics of arm movements (see Biryukova, Roby-Brami, Frolov, & Mokhtari, 2000; Dapena, et al., 2006; Williams, et al., 2010). Biryukova *et al* (2000), for example, employed technologies of this kind to demonstrate a method of collecting data relating to multi-joint movement in human test subjects in general terms[49].

[49] It also is worth noting that since the publication of Biryukova *et al’s* study, which employed the ‘Fastrack™ Polhemus system’ (Biryukova, et al., 2000: 986), a number of advances have been made in motion capture technology that would present numerous different options regarding test design (see, for example, http://www.polhemus.com/motion-tracking/overview/).

Relating specifically to the motions associated with knapping, Williams, Gordon and Richmond conducted a study that focused on exploring the roll of the wrist during stone tool production. This research used the VICON system, which employs high-speed cameras to record markers applied to test subjects' limbs, thereby allowing kinematic data to be collected, included data relating to velocity, acceleration and joint angles (Williams, et al., 2010: 136). Similarly, Dapena, Anderst and Toth explored the biomechanics of arm swing in stone tool production by utilising a system where the actions of a knapper were filmed with two cameras and then subsequently 'digitized' to allow anatomical body landmarks to be measured and the joint torques to be computed (see Figure 8.2) (Dapena, et al., 2006: 334).

Potentially, the core surface could also be designed to capture data relating to the force of the hammerstone blow. Rolian, Lieberman and Zermeno, for instance, designed a proxy hammerstone that has various load cells to record the forces associated with hard hammer percussion (2011: 30-31) (see Figure 8.3). Though Rolian *et al* aimed to measure and compare the magnitude of external/internal forces and joint stresses in the radial digits during hard hammer percussion and flake use (2011: 26), one can conceive of a similar approach being used to measure the critical variables that contribute to successful flake removals in hard hammer percussion (i.e., blow angle, blow strength, blow precision).

Another positive consequence of Rolian *et al's* research is that it suggests that simulating hard hammer-type tasks using of a 'proxy core' that does not involve actual flake removals is a workable approach (2011: 31). I propose adopting a similar approach, where test participants strike a substitute core that registers the blow strength, blow angle, and blow precision as a co-ordinated whole. Though no flakes will actually be removed from the

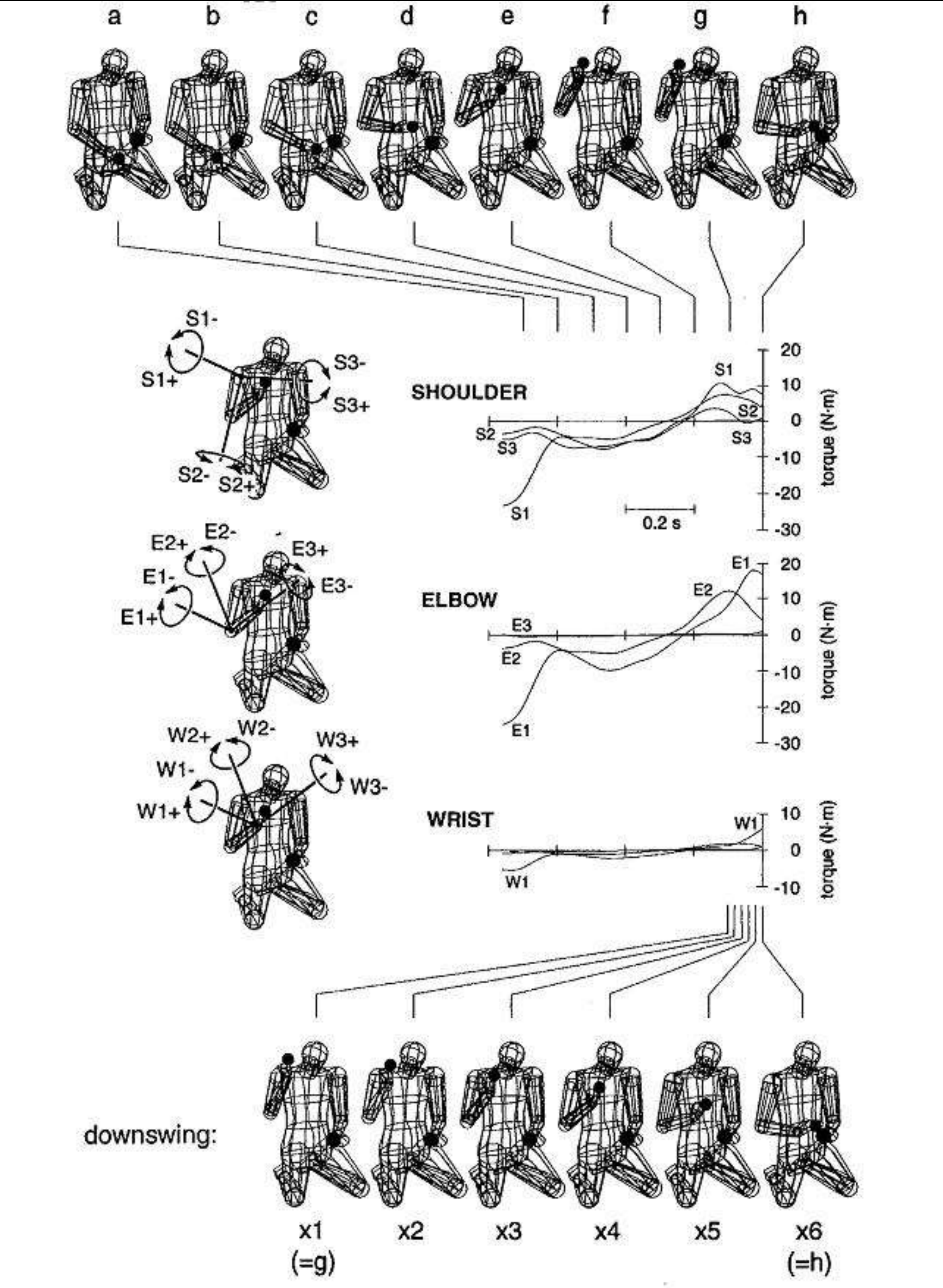


Figure 8.2: 'Wireframe' computer graphic generated using 3-dimensional motion analysis. This method of data collection recorded torques at the joints in the swinging arm during a knapping task (after Dapena, et al., 2006: 335).

core itself[50], whether a particular hammerstone blow is successful in removing a flake could be indicated by a red or green light to indicate success or failure.

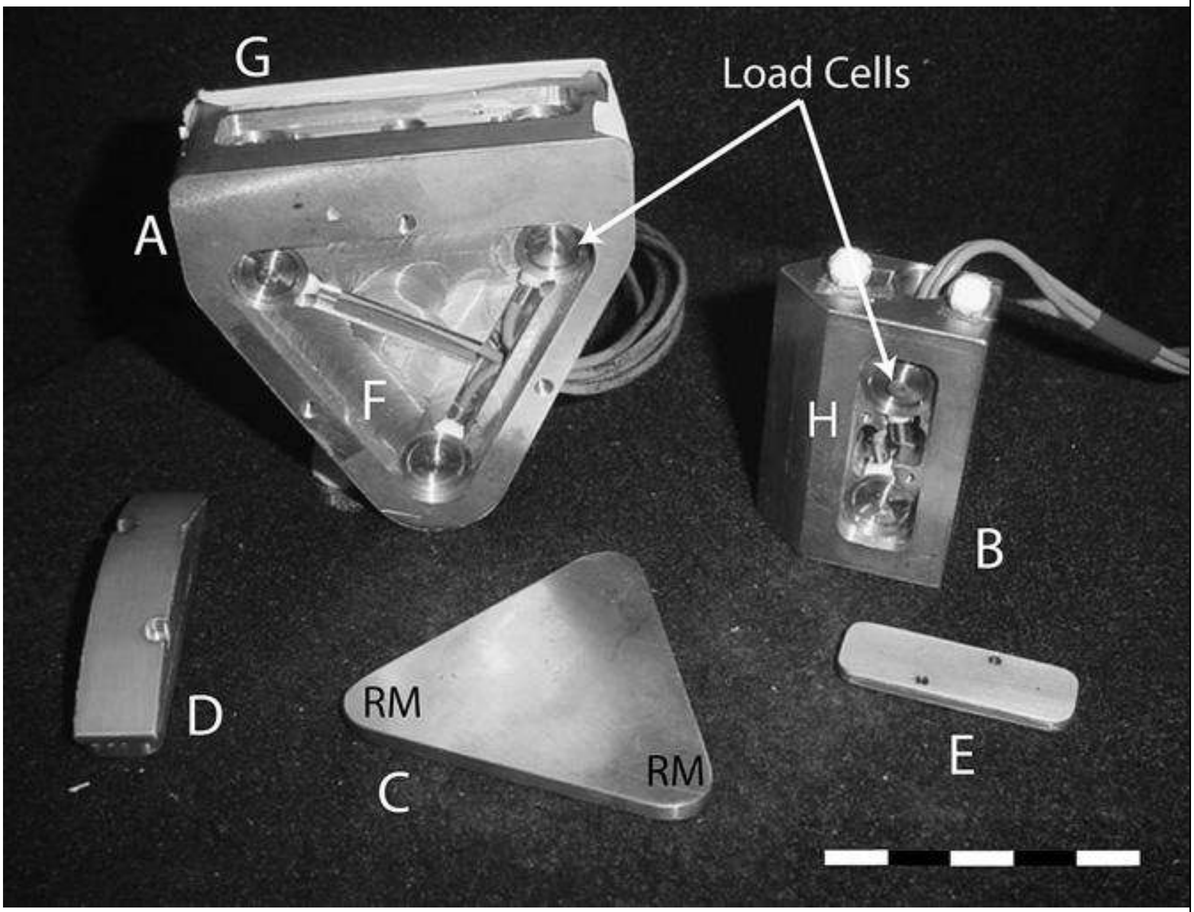
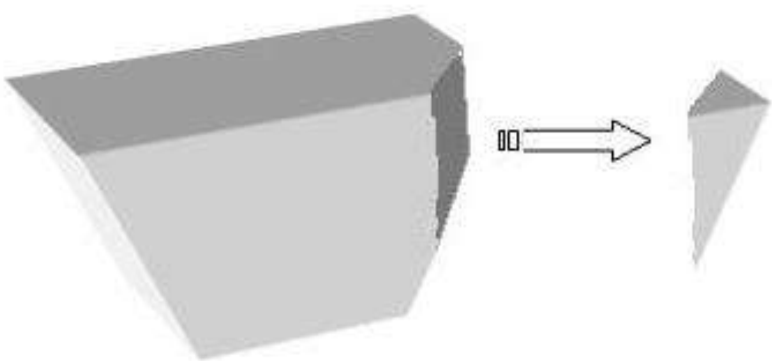


Figure 8.3: Rolian et al (2011) employ a proxy hammerstone (A) and flake (H) to record the forces associated with hard hammer percussion and Oldowan flake use. Most relevant to the present discussion, the hammerstone (A) is made of brass with wells to house load cells to measure reaction forces dynamically during simulated hardhammer percussion. Subjects were asked to use a 'three-jaw chuck grip' to strike a cylindrical vulcanized rubber "core", with the load cells were arranged to record forces associated with the thumb (the three cells set in a triangle in section 'F') and index finger (the two cells in section 'G') (after Roilian 2011: 30-31).

Alternatively, a more complex test design could indicate the success or failure of a flake removal via a simulated visual representation of the core on a television screen[51] (see

[50] It is conceivable that a core could be designed with removable flakes that detach only when a given blow strength is attained, while other variables could be factored in afterwards to determine if the removal would in fact have been successful, but for present purposes the focus will be on a simple moulded plastic core.

Figure 8.4). With the visual representation test subjects would be able to observe not only whether the blow was successful, but would also be able to observe the shape of the flake removed; such information may indeed be necessary for learning how different combinations of the active variables affect the task at hand.



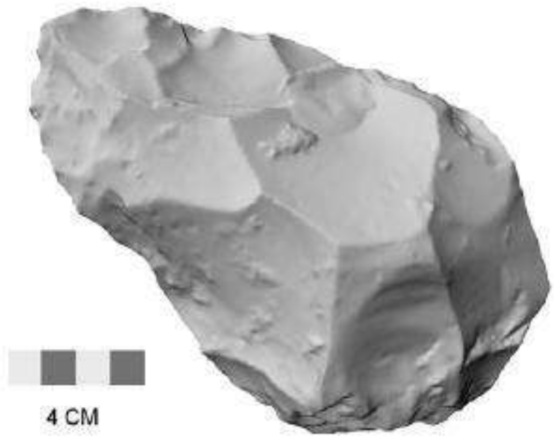


Figure 8.4: Conceivably, test subjects would be able to observe the results of each blow (top) on a screen which produces a simulation of the actual core struck in the experiment. Using 3-D scanning technology a potentially high degree of detail can be obtained for the metric parameters of a virtual core (*bottom*), which could be used to provide visual imagery to test subjects (after Grosman, et al., 2008: 3105)

[51] Recent advances in 3-D scanning of the metric parameters of lithic artefacts could be employed in this case (see Grosman, Smikt, & Smilansky, 2008). Such technology could be used to produce an exact match between the moulded core used by test participants and the simulated representation of the core on screen (see Figure 8.4).

Prior to testing, the proxy core would be calibrated so that the simulated fracture properties it exhibits are close to those conditions that would have prevailed in the EEA. Consulting expert knappers and gaining their feedback would be crucial in this respect to ensure that the system mimics naturally occurring stone as closely as possible. The intended outcome would be a set of parameters for each exterior platform angle presented by the core that specify whether a blow results in a successful flake removal, no flake removal, or a sub-optimal flake removal. As noted previously, this involves a trade off between the blow strength, the blow precision, and the blow angle, with each variable can be assigned a +/- margin of error. Again, the feedback of expert knappers will be crucial for establishing what is appropriate in terms of margins of error for each variable prior to testing. In this way, one can gradually hone the qualities of the proxy core until it has the 'feel' of naturally occurring stone.

8.6. Varying the Parameters of the Task Domain

For the purposes of testing, calibrating the core to mimic the properties of naturally occurring stone would present a test condition where the cause (the independent variable) is present for test subjects. The next step would involve devising alternative core calibrations where the independent variable is manipulated on various levels, so that the simulated fracture properties of the proxy core deviate from naturally occurring stone. In effect, I would argue that such manipulations would amount to creating a virtual version of slint. With reference to the variables that contribute to success in the hard hammer task domain, below I will consider how adjustments can be made for blow angle, blow strength and blow precision on the proxy core.

8.6.1. Blow Angle

When learning to select an appropriate blow angle, Whittaker suggests that novice flint knappers can benefit from a mental rule of thumb called the 'cone model'. This involves envisaging a 'hertzian cone of force' spreading from the point of the hard hammerstone blow through the lithic material, which allows one to predict how a core will fracture (Whittaker, 1994: 97). The cone model can also be usefully employed to illustrate how changing the parameters of what is 'normal' for conchoidally fracturing stone can alter the dynamics of the task domain under consideration.

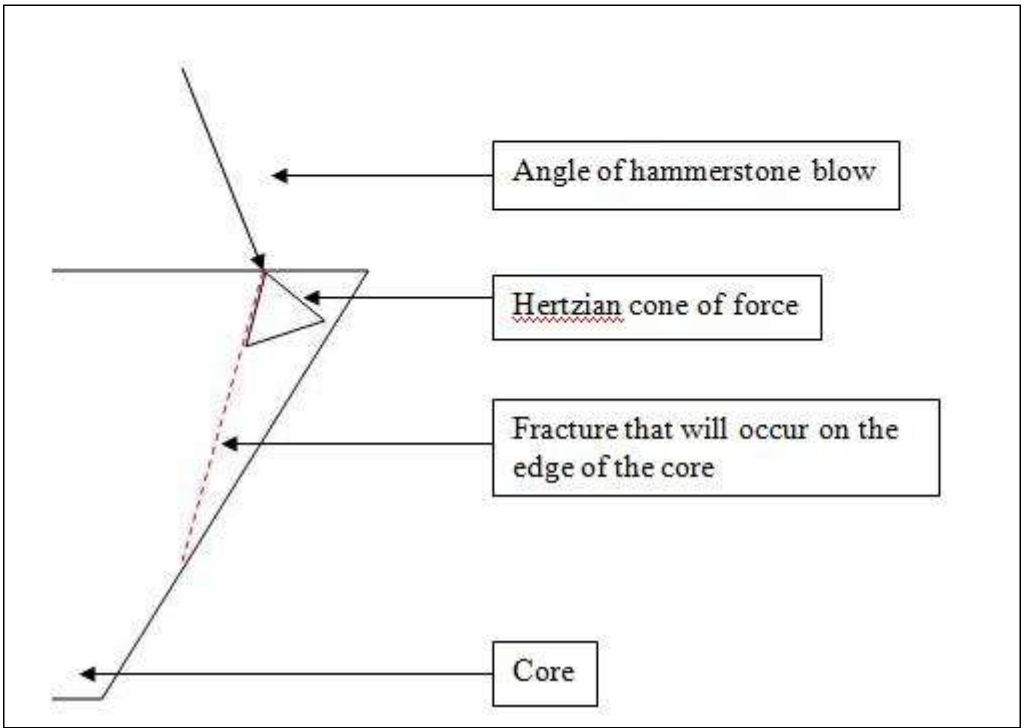


Figure 8.5: Two dimensional diagram of the 'cone model'. Whittaker suggests the cone model can be used as a mental aid to envisage how force of a hammerstone blow spreads through the core (adapted from Whittaker, 1994: 98).

For example, consider Figure 8.5, which illustrates a two dimensional representation of the cone model. From the point of impact of the hammerstone blow, the hertzian cone of force spreads through the core, with the red dotted line representing the fracture that will occur as a result of the blow. When deciding at what angle a hammerstone blow needs to be struck, using the cone model therefore provides the knapper with a ‘mental aid’ to assist in the learning of the task (Whittaker, 1994: 97).

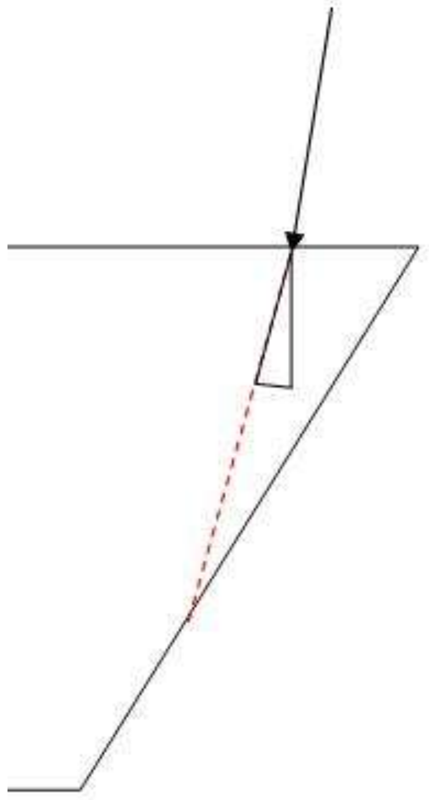


Figure 8.6: Cone model with a reduced angle of hertzian cone. Note that the successful removal of a flake requires a more obtuse blow angle when compared to Figure 8.5 (adapted from Whittaker, 1994: 98).

Employing the same mental aid, it is possible to demonstrate how changing the properties of the hertzian cone of force can change the task domain under consideration. By reducing the angle of the hertzian cone, as in Figure 8.6, the successful completion of the task now requires a blow from an obtuse angle. Conversely, in Figure 8.7, increasing the angle of the hertzian cone necessitates a more acute blow angle (one which, under normal circumstances, might result in only a glancing blow).

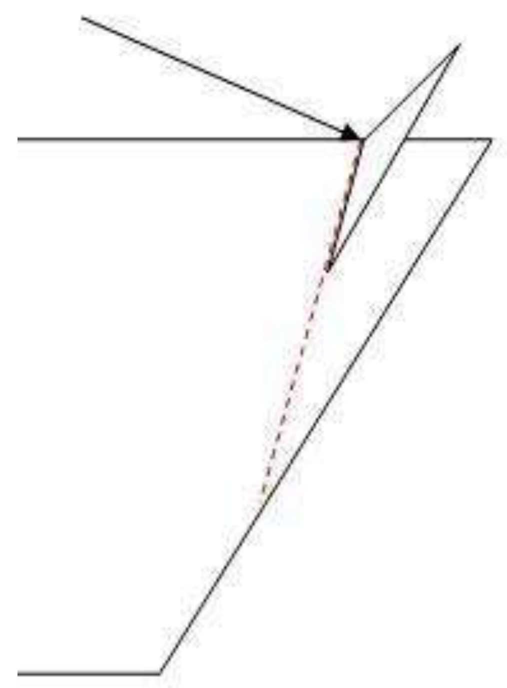


Figure 8.7: Cone model with an increased angle of hertzian cone. Note that the successful removal of a flake requires a more acute blow angle when compared to Figure 8.5 (adapted from Whittaker, 1994: 98).

For the purposes of test design, one can mimic these effects on the proxy core by manipulating this variable to the extent that successful flake removals require the selection of blow angles that would not have been appropriate for hard hammer percussion activities in ancestral environments.

8.6.2. Blow Strength

As with blow angle, what is required in terms of blow strength to successfully remove a flake on the proxy core can also be manipulated. Following the calibration phase, where ‘normal’ blow strengths (together with a margin of error) will have been assigned to each exterior platform angle on the proxy core, this variable can be adjusted for any given platform angle so that a harder or softer blow elicits a successful flake removal. Arguably, however, only the latter is a viable option for experimental purposes, due to the fact that increasing the required blow strength in the task would inevitably create a bias in the experiment design.

Whittaker, for example, notes that increasing the strength of a hammerstone blow usually has a detrimental effect on blow accuracy (1994: 98). Any increase in the strength of blow necessary for flake removal on the substitute core would therefore make the use of stronger blows, which are harder to place with precision, an obligatory part of the task; as a result the task domain is rendered inherently more difficult.

Conversely, the same difficulties are not encountered where the required blow strength on the substitute core is reduced. In the case of a reduction in the required blow strength, the test subjects would have to learn what strength of blow is appropriate in conjunction with the other parameters. The task domain therefore varies from what would be typical in the EEA, but the task is not made inherently more difficult as a result. There is the converse danger, of course, that the task will be made easier. This problem is not insurmountable, but it does necessitate the adoption of a specific model of how the strength of blow contributes to the success of the hard hammer percussion technique.

As mention in previous chapters, there are two viable models in this respect: the ‘threshold model’ and the ‘margin of error model’. The former, supported by experimental work into fracture mechanics, states that the strength of a given blow need only meet a threshold to engender a flake removal (Dibble & Pelcin, 1995: 435; Dibble & Rezek, 2009: 1952). The latter, in contrast, posits an 'ideal' blow strength for any flake removal with an accompanying margin of error; where a blow errs too far from the ideal blow strength knapping errors can result (such as hinge/step terminations) (Pelegrin, 2005; Whittaker, 1994). Arguably, only the latter can be adopted for the experiment design, for reasons outlined below.

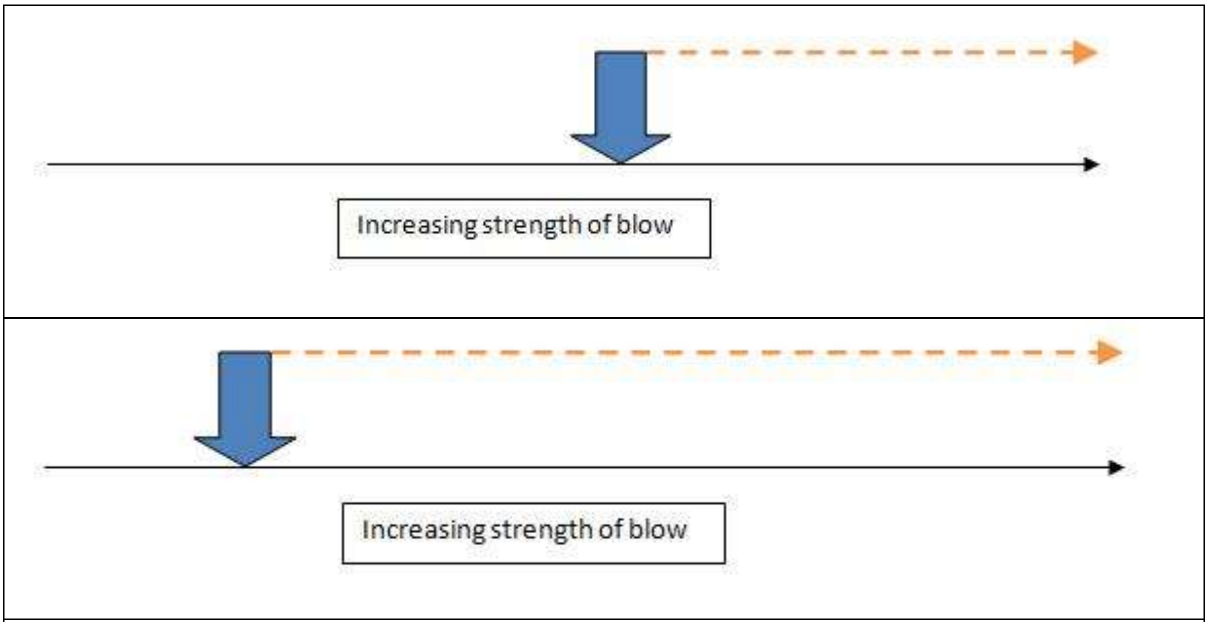


Figure 8.8: The threshold model for blow strength. Diagrammatic representation of the range of possible blow strengths under the threshold model for EEA conditions (top) and in conditions where the blow strength is reduced (bottom). In each diagram the blue arrow represents the ideal blow strength, while the orange arrow depicts the range of potentially successful blow strengths that exceed the ideal. Note that the adoption of the threshold model for the purposes of test design would therefore introduce an unnecessary bias by allowing test subjects learning in non-EEA conditions a much broader range of potentially successful blow strengths.

The threshold model is arguably not feasible for testing due to the fact that it biases the test design to favour subjects learning under non-EEA conditions (i.e., where a reduced blow strength is required to remove flakes). For instance, see Figure 8.8, which presents a diagrammatic depiction of the range of possible blows that are feasible for test subjects under the threshold model for EEA and non-EEA (reduced blow strength) conditions. It is because of this expanded range of potentially successful blow strengths that the threshold model cannot be adopted for the experiment design under discussion.

Where the threshold for blow strength is much reduced a larger range of blow strengths will be adequate for removing a flake. This will not only make the judgement of blow strength easier, but may also make controlling the other variables an easier prospect. In contrast, when the core is calibrated to mimic EEA conditions there is a much more limited range of potentially successful blow strengths. Parity is therefore not retained between the two task domains, because judging the weight of a blow is a much easier prospect when the required blow strength is reduced under the threshold model.

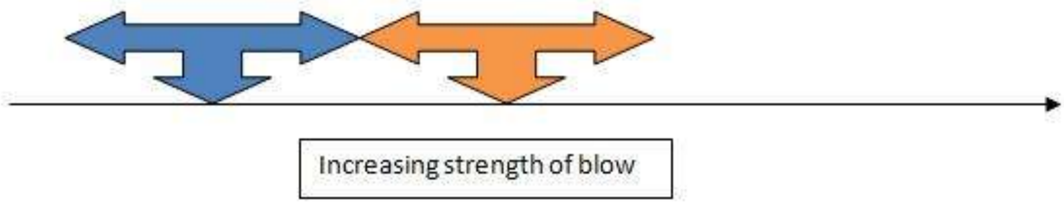


Figure 8.9: The margin of error model for blow strength. The downward orange arrows represent an ideal blow strength for EEA conditions, together with +/- margins of error (left and right arrows) which set the limits for how far a given blow can deviate from the ideal blow strength while still successfully removing a flake. The blue arrow (non-EEA conditions) represents the same margins of error, but the parameters for a successful blow are shifted down the scale in order to reduce the required blow strength. In contract to the threshold model in Figure 8.8, note that this model retains equivalent breadth in terms of margin of error between the two conditions.

In contrast to the threshold model, Figure 8.9 illustrates the margin of error model for blow strength[52]. Note that, unlike the threshold model, the margin of error model does not

[52] Note that the margin of error model depicted in Figure 8.7 assumes that the requirements for the other variables have been successfully met. Indeed, errors in the blow angle and blow precision may serve to reduce the margins of error for blow strength depicted in Figure 8.7. If, for example, a test subject strikes further back on a platform than they intended, what counts as an ideal blow strength would increase, and the +/- margin of error will be reduced.

afford a greater range of possible blow strengths. The same range of possible blows strengths apply for both EEA conditions and reduced blow strength conditions; any deviation outside of that range will result in an unsuccessful blow. Indeed, one could even introduce different scenarios depending on the degree to which the blow strength is underestimated or overestimated. Blows that are too soft could result in no flake removal at all, or an error, such as a hinge fracture. Conversely, blows that are deemed to be too forceful could result in a crushed platform, or an overshooting flake.

The margin of error model therefore forces the test subjects to adapt their actions in terms of what strength of blow is appropriate for the particular core being struck. Given that the aim of the experiment is to compare how efficiently subjects learn to utilise hard hammer percussion in conditions that mimic the EEA on the one hand, and in conditions that diverge from it on the other, I would argue that the margin of error model is best suited to achieve this purpose.

8.6.3. Blow precision

As alluded to above, requirements regarding blow precision on the proxy core cannot be varied without biasing the test results one way or the other. Recent experiments designed to identify the skills that novices need to master in order to become expert knappers (see Geribàs, et al., 2010) suggest that expert knappers have an ability to deliver consistently accurate hammerstone blows, while novices do not. If the substitute core is given more lenient parameters regarding what counts as a precise blow, one risks making a complex skill associated with the task domain much easier to achieve. As a result, those test subjects learning under conditions that mimic the EEA have a more difficult task to complete, which would prevent any meaningful comparison.

The same objection applies for increasing the required blow precision on the substitute core. If one increases the degree of blow precision required, one biases the results by making the task unreasonably difficult. As a result, the requirements for what counts as an adequately precise blow would need to be kept constant throughout, and as close to the original task domain as possible. In terms of results, what matters is how the test subjects learn to produce consistently precise hammerstone blow in conjunction with the other variables (which may, or may not, mimic EEA conditions). For each viable flake removal on the proxy core, therefore, one would require an ideal blow placement, coupled with a restricted +/- margin of error.

8.7. Soft Hammer Percussion

Though the above has focused on the practicalities of test design for the hard hammer percussion task domain, the creation of a practical test for the soft hammer percussion technique would follow the same principles in terms of manipulating the variables involved. The necessary changes would obviously need to be made regarding the original proxy core, which would need a morphology conducive to soft hammer removals, but the variables could be manipulated in much the same way as for hard hammer percussion.

One issue that would necessitate a different approach for testing learning efficiency for soft hammer percussion behaviours concerns the required prior grounding in the hard hammer percussion technique. As mentioned previously, archaeologists cite the use of hard hammer percussion in the ‘roughing out’ phase of core preparation for soft hammer percussion (Newcomer, 1971; Whittaker, 1994; Winton, 2005). One can therefore posit that individuals learning soft hammer percussion would have already built up a degree of technical competence in the hard hammer percussion task domain. Indeed, it seems unlikely that prehistoric knappers would have commenced the learning process with soft hammer percussion exclusively. The logical focus of initial test design would therefore be on the hard hammer percussion task domain, though it would be feasible to utilise subjects from hard hammer percussion test situations (both EEA and non-EEA) to subsequently examine how efficiently soft hammer percussion skills are acquired.

8.8. Testing for Psychological Mechanisms Relating to Method In Practice

The process of test design for examining skill acquisition for stone tool production methods would ideally involve extending the practical realisation of the slint/flint test outlined above to allow sequences of flakes to be removed. Indeed, the primary aim of test design would maintain: one’s aim is to test how well the skills pertaining to stone tool production methods are acquired in two sets of conditions – those that closely mimic those of the EEA, and those that differ from it through various levels of manipulation of the independent variable.

The most pressing practical challenge of testing in this instance centres on how data are collected for multiple flake removals. I would argue that there are two viable approaches to test design in this instance, with each enjoying their respective advantages and drawbacks. One approach would involve attempting to retain the ‘real-world’ percussive aspects of the task utilising the proxy core outlined above. Another approach would involve by-passing the physical aspect of method application, and instead focus on testing the mental ability of the test subjects to complete abstract tasks of equivalent complexity.

8.8.1. Proxy Core Method Test

An immediate and significant obstacle to the use of a proxy core for testing stone tool production methods is the absence of actual flake removals. Since the method task domain is primarily concerned with achieving intermediate and ultimate goals, contingently worked towards through the sequential removal of flakes from the core, this presents an obvious problem. A possible means to address this issue would involve using sequences of moulded cores that reflect successive flake removals (see Figure 8.10). Test subjects would begin the test with a complete moulded core presenting various viable platforms. When a flake is successfully removed (in accordance with the fracture properties attributed to the core), a second moulded core would be presented to the test subject with a morphology adjusted to reflect the removed flake. Each time the subject removes a flake, another amended core is presented, effectively allowing the test subject to remove sequences from the original moulded core and observe how the mass is reduced[53].

The main advantage of this approach to test design would be the retention of the percussive/technical facets of the task domain, as well as the physical presence of the core itself, which the test subjects can examine in the decision making process. The main disadvantage, notwithstanding the unavoidable necessity of constantly replacing the proxy

[53] Note that technological advances in both scanning technology and 3-D printing make it quite feasible to produce a series of successive core morphologies with the requisite levels of detail to allow method-related decisions to be made by test subjects (Grosman, et al., 2008; Riel-Salvatore, Myungsoo, McCartney, & Razdan, 2002). Indeed, these could be based on actual examples of lithic reduction.

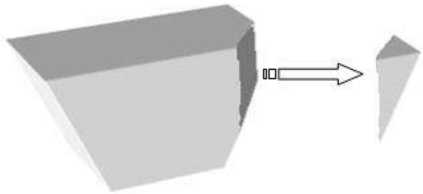
	*Stage 1:* Test subject is presented with a core with numerous viable platforms for flake removals.
	*Stage 2:* Test subject successfully removes a flake from the core.
	*Stage 3:* Test subject is presented with a second core with an amended morphology to reflect the first flake removal.
	*Stage 4:* Test subject successfully removes a second flake from the core.
	*Stage 5:* Test subject is presented with a third core with an amended morphology to reflect both the first and second flake removals.

Figure 8.10: Illustration of a possible test design for method skill acquisition employing a substitute core. A test subject would begin with a moulded core (stage 1) which presents various viable platforms for flake removals. With each successive flake removal a core with an amended morphology is presented to the test subject (stages 2-5). In this way subjects can be tested regarding how well they can engender multiple flake removals from a substitute core. Though the above suffices to illustrate the proposed test design, 3-D scanning technology could, as mentioned previously, be employed to produce a detailed and sophisticated visual representation of the core (Grosman, et al., 2008: 3105).

core, would be the need to map out the myriad possible flake removals as per the fracture properties attributed to the core.

To ensure the fidelity of the task one would also need to incorporate not only successful flake removals, but also removals which are sub-optimal that result in core features that present further challenges to the test subjects. Otherwise one risks presenting a simplified dichotomy to the test design where a flake is either successfully removed or not, which would arguably result in a distorted channelling of the decision making process and bypass an important aspect of the method task domain (i.e., the necessity of contingency in the decision making process when flakes detach in a way that deviates from the intentions of the knapper). Taking such factors into account would obviously introduce a considerable degree of complexity to the process of test design, and require significant investment in terms of prior planning to map out both the numerous possible successful reduction choices the test subject may attempt, as well as the various errors (arguably even more numerous still) that would result where mistakes are made.

8.8.2. Abstract Method Test

A second possible approach to test design when examining skill acquisition for stone tool production methods would involve the creation of an abstract, virtual representation of the method task which retains the important conceptual problems encountered in the task domain, but dispatches with the practical aspects. For example, one could design a virtual 'Method Game' with which test subjects would engage. The Method Game would consist of a computer-generated simulation of a 3-dimensional core. In accordance with the intermediate and ultimate goals, test subjects would make choices regarding the various parameters relating to the flake removal process: i.e., they would choose the blow placement, the blow strength, and the blow angle for each attempted flake removal.

The visual representation of the core would be updated in real time to show the outcome of each removal attempt: i.e., whether the blow was successful, unsuccessful, or successful but in some sense sub-optimal. As with the tests outlined above, the fracture properties of the core would be open to manipulation, allowing researchers to test the ability to test subjects to learn to solve method-related problems under conditions that mimic, or deviate, from those that would have been prevalent in the EEA of stone tool production. This approach to data collection is somewhat analogous to computer games that mimic sports. For example, golfing computer games incorporate a degree of the complexity of the task at hand (i.e., club selection, judging blow strength, shot direction in accordance with other contributing factors such as wind speed) while bypassing any associated real-world, physical motor skills[54].

In terms of advantages one could argue that the Method Game would be comparatively easier to administer than the test design above that retains the physical aspects of the task, while the data collection process would be more streamlined in the absence of motion capture technology. The use of the Method Game would also afford researchers the opportunity to test alternative hypotheses regarding skill acquisition in the method task domain. For example, it would allow one could to introduce test subjects to method-type tasks in the absence of prior grounding in technique, which may offer various opportunities for comparative purposes regarding our cognitive abilities in this area.

[54] This approach would also make the inclusion of various nuances of the method task domain more feasible; i.e., the selection of different sized hammerstones, or the switching from a hard to soft hammer percussor.

A potentially fruitful area for research here would be to examine the role that memory plays in solving method-type problems. Wynn (1993a: 396) and Wynn and Coolidge (2010: 101), for example, argue that selection pressures would have been present over time favouring increases in both working memory and long-term memory capacity for method-type problems. However, they also note that any level of expertise takes years to acquire, where repetition of the task and experimentation within the task domain results in more elaborate procedures being encoded in the long-term memory (Wynn & Coolidge, 2010: 98). Having an abstract task on which test subjects can practice presents a much less labour intensive means to examine how retrieval structures are built up and, more importantly, whether they are established more readily in conditions that are closer to those prevalent in the EEA of stone tool production.

In terms of disadvantages, one potential drawback of the Method Game is that it may present a task that is too abstract in nature. As Field and Hole state:

> 'The obsession with control and manipulation of variables in experiments can result in some very artificial situations and alien environments, so the resulting behaviour we observe in people may not be representative of how they would respond in a more natural setting.' (2006: 26)

Despite the opportunities presented to focus only on test subjects' cognitive abilities in method-type tasks, the fact that the Method Game would circumvent any physical aspects of the task could be similarly cited as a major weakness. Indeed, it may be the case that skill acquisition in the task domain of stone tool production techniques provides crucial grounding for subsequent method learning. For example, from an ethnographic study into the knapping behaviours of stone-bead knappers in Indonesian Irian Jaya, Stout observed that: '…mastery of forces involved in individual flake removals is an essential pre-requisite for the emergence of effective knapping plans' (Stout, 2005: 274).

If we assume for a moment that the human cognitive architecture does contain psychological mechanisms dedicated to facilitating the solution of method-type problems, it remains a possibility that prior experience of learning stone tool production techniques provides an adaptive trigger for subsequent engagement in the method task domain. This would be problematic for the interpretation of results from tests where the Method Game is employed, because in instances where one observes no discernible difference in learning efficiency it would be difficult to conjecture whether this was due to the absence of a crucial facet of the EEA of stone tool production (i.e., prior familiarity with stone tool production techniques) or an underlying domain-general ability to engage in the task at hand. I would argue that this problem can be addressed, though it would involve introducing additional levels of complexity to the test design. For instance, one could prime test subjects in technique application in EEA and non-EEA conditions before progressing to the more abstract task of the Method Game in those respective conditions.

A final point that needs to be made regarding both the method test designs outlined above concerns the issue of expertise. Though it was noted above that the Method Game could potentially be employed to examine the role that memory capacity plays in the attainment of expertise, for the initial phases of testing in the method task domain it would be neither necessary nor expected that test subjects acquire the skill levels necessary for applying methods such as the biface and Levallois. In both test designs the subjects would begin as novices, with, at most, a degree of experience in applying stone tool production techniques. This is necessarily so, since the aim of the test design would be to compare the efficiency of learning in a method-type task domain for test subjects in an EEA and non-EEA conditions.

The kind of task presented to the subjects would therefore be closer to the initial stages of method learning. For example, Callahan cites several phases that need to be learned in biface manufacture, and also notes that they need to be practiced and mastered in a sequential fashion before the method as a whole can be attempted from start to finish (Callahan, 1979: 36-38). The kind of the task presented to test subjects initially need not, therefore, be any more complex than attempting a modest sequence of flake removals to produce a desired morphological feature on a core. Further levels of complexity could then be added, with additional intermediate goals, where the proficiency with which the initial phases are completed has ramifications for the ongoing viability of the task.

8.9. Conclusion

To conclude, in the above chapter I considered possible approaches to experimental test design to examine whether psychological mechanisms dedicated to solving the information processing problems of the task domains of stone tool production techniques and methods are present in the human cognitive architecture. I began by outlining the steps involved in test design in psychology generally, before elucidating the specific commitments required in the test design process as per the methodology of Evolutionary Psychology.

I argued that the most relevant cause and effect relationship for the stone tool production task domain is that which pertains between the conchoidal fracture properties of the raw material used in the task and the efficiency of learning of stone tool producing behaviours.

I then proposed an ‘in principle’ test design (termed the ‘slint/flint test’) to examine whether a causal relationship exists between the two variables cited. This test design aimed to compare the efficiency of learning for two groups of test subjects in the stone tool production task domain for two different scenarios: one in which the independent variable is present (i.e, flint is the raw material) and one in which the independent variable has been manipulated (i.e., slint is the raw material). This experimental design has the potential to test for psychological mechanisms in the human cognitive architecture, because if psychological mechanisms attuned to solving the information-processing problems of stone tool production are present then one would expect the learning process to proceed most efficiently where the learning environment most closely matches that of the EEA.

Finally, I considered the possibility of realising the ‘in principle’ test design in practice. For stone tool production techniques, I proposed a test design incorporating a proxy core on which the test subjects would attempt to deliver blows to remove flakes. Though the core itself would not fracture, the variables of the task domain of technique (blow angle, blow force and blow precision) would be recorded using motion capture technology, allowing one to inform test subjects as to whether a blow was successful, unsuccessful, or successful but sub-optimal. This design, I argued, allows one to manipulate the parameters of what counts as a successful blow on the proxy core, and it therefore becomes feasible to test the efficiency of learning of stone tool production techniques in EEA and non-EEA conditions.

For stone tool production methods, I argued that there are two possible approaches to test design: namely, one where the physical aspects of the task are retained and one where they are replaced by an abstract task. Regarding the former, I argued that it is feasible (though arguably cumbersome) to utilise a series of proxy cores to test how well subjects engage in successive flake removals. This can be achieved, I argued, by mapping possible flake removal paths and presenting test subjects with an adjusted core with a morphology reflecting a flake removal each time one is successfully removed. Regarding the latter, I argued that one could create an abstract ‘Method Game’, where test subjects would engage with a 3-dimensional, computer-generated simulation of the core, and attempt successive flake removals by selecting appropriate combinations of blow placement, angle and force. For both of these proposed designs, the manipulation of the fracture properties of the core remains feasible, and therefore one could similarly test two groups of subjects in conditions that closely mimic or deviate from those of the EEA.

Chapter 9: A Mixed Method Experimental Design for Testing Consistency in Blow Strength Judgment in a Knapping Task

> 'Mismatches between ancestral and current EEAs specific to particular adaptations may cause an adaptation to malfunction. This malfunction may be caused by different immediate or different developmental environments. If an adaptation is malfunctioning because of adaptation-environment mismatch, it may be because the operational adaptation is in some way malformed or incompletely developed because of inadequate or inappropriate interactions during development.' (Crawford, 1998: 283)

9.1. Introduction

The aim of this chapter is to describe the methods employed to collect data relating to various aspects of novice performance during a knapping task. A mixed methods, explanatory sequential design was employed that consisted of two distinct phases: a first phase of quantitative data collection followed by second phase of qualitative data collection (Creswell & Plano Clark, 2011: 71). The need for a mixed methods approach was deemed necessary as a result of issues that arose from the quantitative data collection phase, and can therefore be considered emergent rather than fixed in nature (Creswell & Plano Clark, 2011: 54).

In previous chapters three variables were identified as contributing factors to success or failure when removing flakes during knapping tasks (i.e., judgement of blow strength, blow accuracy and blow angle). The aim of the first phase of quantitative data collection was to isolate and collect data relating to one of these facets: the judgement of blow strength. The decision to focus on this aspect of the task was taken for three main reasons: first, focusing on a single criterion made the task more achievable. For novice knappers this is particularly important, because they inevitably lacked the skills necessary to attend to multiple facets of a knapping task. It was anticipated that requiring novices to divide their attention between multiple variables from the outset would risk overwhelming them and prevent any meaningful data to be collected regarding any of the variables.

Secondly, the focus on the judgement of blow strength was selected due to the fact that it represents one of the most immediate skills to be mastered when learning to knap. As noted in previous chapters, regardless of how well the precision and blow angle are judged by the knapper, misjudging the strength of a blow can produce various problematic features on the core (such as step hinges), or can lead to the platform being shattered. Lastly, in considering possible test designs for examining novice's ability to control the three variables, it was decided that testing judgement of blow strength presented the most practicable option for test design.

Drawing broadly on the methodology of Evolutionary Psychology, the test design for gathering data relating to the judgment of blow strength by novice knappers in a knapping task aimed to compare two differing conditions: those that would have been invariably encountered in the EEA of the techniques and methods of stone tool production, and those conditions that deviate from the EEA. To achieve this it was necessary to initially define a knapping task (i.e., a single flake removal with a hard hammer) with the help of an expert knapper.

In order to gather data in conditions that deviate from those typically used in the knapping task, test participants were invited to administer hammerstone blows onto recording apparatus using only their own judgement as a guide. It was anticipated that all, or at least most, participants would overestimate the degree of force needed, as is typical for novice knappers (Bril, et al., 2010; Dapena, et al., 2006: 337; Whittaker, 1994: 116). To gather data for the judgement of blow strengths that are typical for the defined hard hammer flake removal task, test participants were given guidance regarding the appropriate strength of blow before being asked to administer a series of blows within that range.

A detailed account is provided below of the research design, the demographics of the test participants, the apparatus and materials employed, and the procedures adopted for testing and data extraction. The design aimed to test the hypothesis that test participants will display better judgement (determinable through greater consistency) when applying blow strengths that are equivalent to those typically encountered in a knapping task, as opposed to those blow strengths that seem intuitively appropriate. The null hypothesis is that there will be no discernible difference between the degree of consistency evident between the two data sets.

Regarding the second phase of data collection, Creswell and Plano Clark note that mixed methods explanatory sequential designs are typically employed to examine new questions that emerge from, but cannot be answered by, the quantitative data (2011: 82). In this instance, potential issues arose during quantitative data collection concerning unanticipated constraints regarding test subjects' choice of body position. An examination of how test subjects viewed various aspects of the task (i.e., body position adopted, the way the core and hammerstone are held, and the way blows are applied) in the absence of such constraints was therefore deemed necessary and potentially informative. With the utilisation of video footage of an expert knapper, it also provided an opportunity to examine the influence of self-learning for novices in the earliest stages of knapping skill development.

As was with the first phase, a detailed account is provided below of the research design, the demographics of the test participants, the apparatus and materials employed, and the procedures adopted for testing and data extraction. The qualitative data collection phase aimed to examine two main questions:

1) In the absence of any constraints, do test participants spontaneously adopt body positions similar to those used in administering hammerstone blows in the first phase?
2) After instruction (i.e., video footage of an expert knapper), are test subjects inclined to change any of the following in a knapping task: body position, core grip, hammerstone grip, blow height, blow lateral movement?

The procedures employed during data collection were devised in accordance with the Archaeology Department's Ethical Policy at the University of Durham and ethical clearance was secured via the Ethics Peer Review Group. To ensure the ongoing anonymity of test subjects, and also to comply with the principles of the Data Protection Act (1998), the data were retained only for the stated purpose of testing (i.e., to extract the required data from the video footage).

9.2. Quantitative Data Collection: 1st Phase

9.2.1. Research Design

The experiments carried out had a 'one group pre test/post test design' (Field & Hole, 2006: 68). The independent variable was the task-appropriate blow strength for the given task as defined by an expert knapper. This variable was manipulated on two levels: i.e., it was either present or absent for test participants (Field & Hole, 2006: 21; Harris, 2008: 128). The independent variable was deemed to be present when test participants were applying blows appropriate for the task (as defined by the expert knapper), and absent when they applied blows in conditions that deviated from it (according to their own judgement).

The outcome variable (dependent variable) was the consistency of the strength of the blows applied. The design used a repeated measures ('within-subjects') design, meaning that all test participants were exposed to all experimental conditions (i.e., all were asked to administer blows both according to their own judgement and with guidance from the principal investigator) (Field & Hole, 2006: 70). Randomization was achieved within the design by alternating the order in which participants were exposed to the two sets of conditions under which data were collected (Field & Hole, 2006: 71), with half the test subjects being asked to administer blows both according to their own judgement first, and half being asked to administer blows following guidance from the principal investigator first.

9.2.2. Participants

For the task definition phase (outlined below) one participant was used: James Dilley, a flint knapper with 10 years of knapping experience. For the testing phase (also outlined below) 12 individuals participated (see Table 9.1). There were 8 male and 4 female participants with ages ranging from 21 to 70; mean age was 41 years with a standard deviation of 18.57. All participants were drawn from existing acquaintances (friends, family and work colleagues) of the principal investigator.

Subject	**Age**	**Gender**	**Occupation**
Subject 1	59	Male	Heavy goods vehicle driver
Subject 2	39	Female	Lecturer (Forensics)
Subject 3	69	Male	Retired - plastic fabricator
Subject 4	64	Female	Retired – accounts worker
Subject 5	27	Male	Student (town planning)
Subject 6	29	Male	Student (structural engineering)
Subject 7	21	Male	Administrative worker
Subject 8	32	Female	Student liaison worker
Subject 9	28	Female	Engineer (working area not related to fracture of brittle solids)
Subject 10	23	Male	IT technician
Subject 11	39	Male	Administrative worker
Subject 12	70	Male	Planning consultant

Table 9.1: Demographic data for the 12 participants who contributed to the quantitative testing phase.

The professions covered by the test participants were: heavy goods vehicle driver (1), planning consultant (1), university lecturer (1) (Forensics), IT technician (1), administrative worker (2), student liaison worker (1), engineer (working area not related to fracture of brittle solids) (1), student (2) (one studying structural engineering and one studying town planning), retiree (2) (former professions were accounting and plastic fabrication). Only one test participant reported previous experience of working with the fracture properties of stone. Though this participant had previously trained as a mason he self-reported that the types of stone used during his apprenticeship were comparatively softer than flint. No inducements were offered to any members of the sample for their participation.

9.2.3. Apparatus and Materials

The following apparatus and materials were employed within the experiment design. A Salter Top-loading Parcel Balance (PAT No. 659716) with a dial scale (Max 10kg/22lb) (see Figure 9.1) was used to record the blow strengths, with test participants being asked to

Figure 9.1: The Salter top-loading, dial scale parcel balance used to record blow strengths. Test participants were asked to strike the hard rubber striking platform with the hammerstone in Figure 9.3.

strike the surface of the scale in order to record the degree of downward force applied. The existing area on the scale providing the striking platform for the percussive blows was initially deemed too small (approximately 1.5cm x 5cm) and therefore needed to be modified due to the potential safety risk to novice knappers (i.e., if a blow glances off the striking platform, or misses the platform, the test participant may risk injuring their hand/wrist on the apparatus). To avoid this risk a silversmith's rubber block (Length 10.0cm, Width 10.0cm, Depth 2.5cm, Weight 365g) was affixed to the top of the scale to provide a more substantial striking platform during the experiments (see Figure 9.2).

Figure 9.2: Top view of the striking platform. The silversmiths rubber block (highlighted in red) provided a striking platform for test participants (Length 10.0cm, Width 10.0cm, Depth 2.5cm, Weight 365g).

A large, ovoid, quartzite hammerstone was used to strike the platform (see Figure 9.3). The hammerstone weighed 780g, which is consistent with previous experimental work utilising hammerstones in flint knapping experiments (Bril, et al., 2010: 4; Dapena, et al., 2006: 334; Geribàs, et al., 2010: 2859; Newcomer, 1971: 85) and within the weight range typically employed for removing the larger flakes associated with the initial roughing-out phase of preparing a biface blank (James Dilley - *Pers. Comm.*).

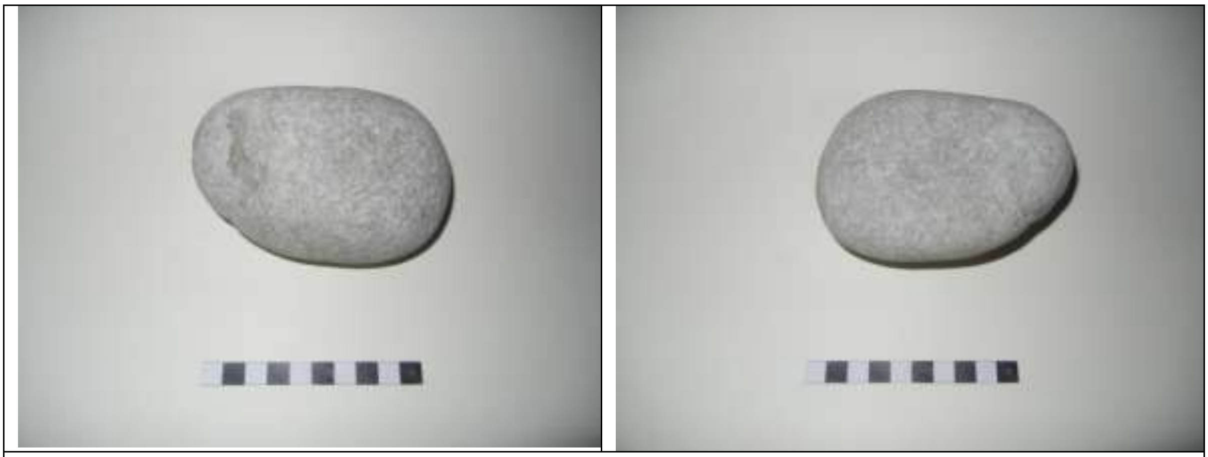


Figure 9.3: An ovoid quartzite hammerstone. The hammerstone (approximate dimensions: 11cm x 7cm x 6cm, with a weight of 780g) that was used by the test participants to strike the platform on top of the scale in Figure 9.1 (scale in cm).

The hammerstone was chosen due to its regular ovoid shape (reducing the risk of it fracturing during the percussive task) and lack of sharp edges (reducing the risk of injury to the test participants). To provide further safeguards during testing participants were also provided with a pair of heavy duty gloves and protective goggles.

Footage of the downward force registered on the dial of the scale by the percussive episodes was filmed using the video function on a Nikkon Coolpix S1800 digital camera. Initial testing of this equipment by the principal investigator showed that frame by frame analysis of percussion events allowed the reliable capture of the maximum extent of needle movement on the dial as a register of the downward force applied.

Finally, sundry other items were utilised during testing, including: a template flint core and flake produced by expert knapper James Dilley (see Figure 9.4) which was made available to test participants to examine in all experiments; a paper ‘pie section’ cut out (see Figure 9.5) was used to provide visual guidance on the dial scale to participants in the training phase (further details are provided in the procedure section below); a standard 30cm ruler was used as an aid to reading off the extent of the movement of the dial during the analysis

Figure 9.4: Photographs of the model flint core and flake produced by expert knapper James Dilley. *Top Row:* Dorsal view of the core with the flake *in situ* (left) and the ventral view of the core (right). *Middle Row:* Dorsal view of the core with the flake removed (left) and the core and flake (right). *Bottom Row:* Dorsal (left) and ventral (right) views of the flake (all scales in cm).

of the video footage obtained; a 2.5 kg weight was used to test the ongoing accuracy of the top-loading scale before and after each test.

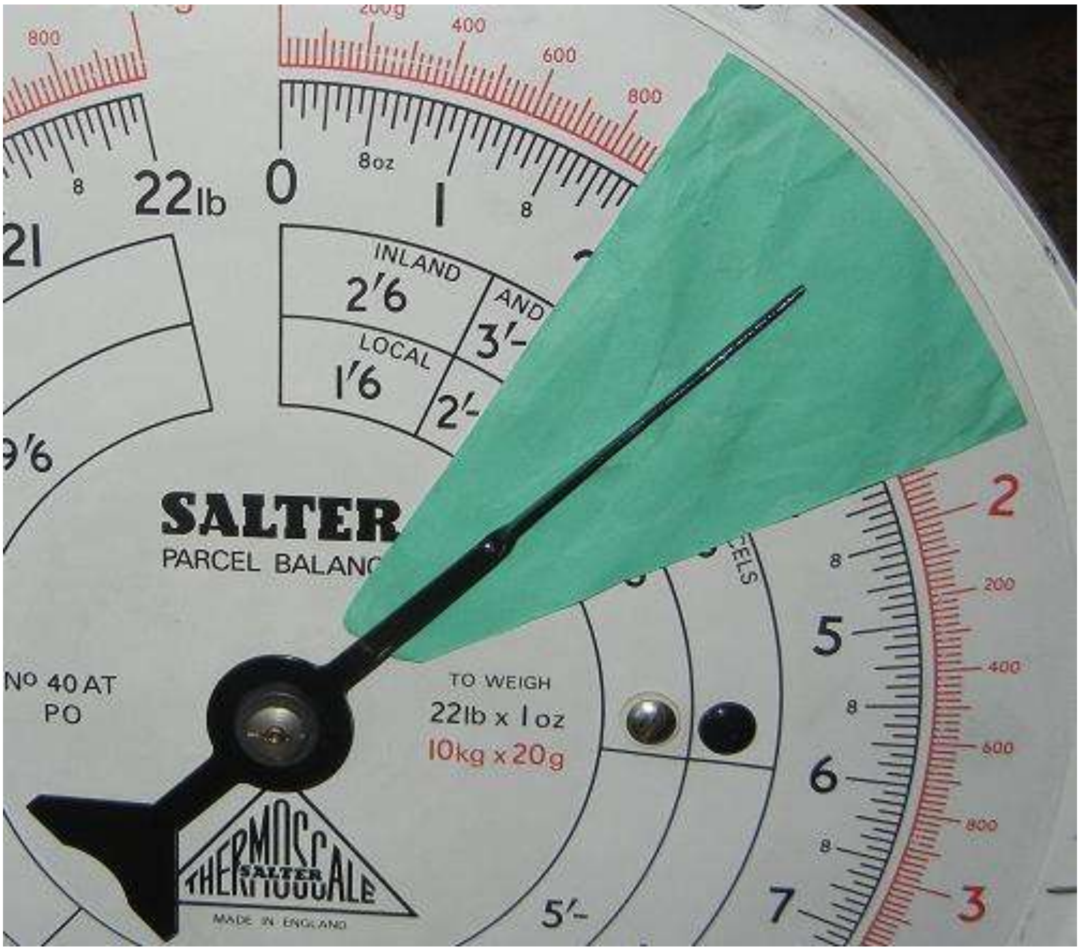


Figure 9.5: The 'pie-section' indicator used during the training phase. Photograph of the face of the scale with a 'pie-section' indicator added to provide visual guidance to test participants of the degree of downward force needed to remove the flake from the core in Figure 9.4.

9.3. Testing Procedure

The procedure employed during testing can be broadly delineated into three stages: the task definition stage, the testing stage, and the data extraction stage.

9.3.1. Stage 1: Task Definition Stage

Since the blow strengths required for knapping exhibit a degree of variation (depending, for example, on factors such as the type of flake being removed and the quality of the raw material) it was necessary to define a specific, invariable flake removal task for the duration of testing; this was achieved during the task definition stage by producing a template consisting of a single flake removed with a single hammerstone blow from a core.

The task definition stage involved working with James Dilley[55]. Initially, James was asked to read the 'Participant Information Sheet' (version 1) (see Appendix Figure A), after which the main points outlined in the document were reiterated verbally; i.e., that he would be asked to partly reduce a flint core using hard hammer percussion, and then apply a series of 10 blows to a top-loading scale. James was then asked to complete an 'Informed Consent' form (version 1) (See Appendix Figure B). The task definition stage did not proceed further until James had verbally agreed that he understood what the task entailed, and had been given the opportunity to ask any questions.

Following this, James was asked to reduce a flint core as per the 'roughing out' stage of the biface method. Mid-way through this core reduction process, James was asked to stop after the removal of a flake that he considered typical for such hard hammer percussion activities. This core and flake were retained for later use in the testing stage as a visual cue for the test participants (see Figure 9.4).

[55] Note: On his informed consent form James Dilley waived anonymity for the study, and verbally requested that he be named in any work that resulted, either published or unpublished.

Once the model flake/core had been created, the blow strength used when removing the flake was recorded. This was achieved by asking James to strike the platform of the top-loading scale 10 times with a blow strength equivalent to that used when removing the flake from the core. The principal investigator recorded the 10 blows applied to the scale with a digital camera.

9.3.2. Stage 2: Testing Stage

The testing stage consisted of a series of tests where 12 participants with no experience of flint knapping were invited to participate in percussive tasks. Participants took part in the experiment individually. Where it was necessary for several participants to be tested consecutively (e.g., when several subjects were available for testing at once, but within a limited time frame), each participant was tested in isolation and no conferring was allowed between individuals who had participated and those still waiting to do so. Randomization was achieved by allocating test participants to two groups and presenting the knapping tasks in one order for one group and the reverse order for the other group.

The principal investigator ensured the ongoing accuracy of the top-loading scale by testing it before and after each experiment with a standard 2.5 kg weight. This was necessary due to the possibility that the accuracy of the scale could have been adversely affected by repeated percussive blows, potentially skewing the recorded blow strengths for later test subjects when compared with earlier participants. No discrepancies were found, however, and the scale was therefore deemed to provide consistent measurements for the duration of testing.

The use of standardized instructions, a recommended practice in designing/reporting methods in psychology (Harris, 2008: 43), was adopted where feasible to eliminate the introduction of bias as a result of differing style, content, or delivery of instruction on the part of the principal investigator. However, in some parts of the experimental design (i.e., the period of training using the pie-slice indicator) the instruction provided necessarily varied due to the idiosyncratic reactions of each participant. As noted below, though experimental conditions varied at this point in terms of the guidance required and provided, all participants were asked to achieve the same outcome (i.e., ability to reliably replicate a given blow strength).

Given the above, the test procedure was applied as follows: one group of 6 test participants were asked to read the 'Participant Information Sheet' (version 2) (see Appendix Figure C). The test subjects were then asked to complete the 'Informed Consent' form (version 2) (see Appendix Figure E). The experimental session only proceeded past this point once the test participants had verbally agreed that they understood what the task entailed, had the chance to ask any questions, and were informed that they were free to leave the session at any time. Before the experiment commenced, the main points of the participant information sheet were reiterated verbally to the test participants; i.e., that it involves a percussive task with 2 stages, each requiring enacting a series of 10 hammerstone blows.

Test participants in this group were first presented with the model core and flake previously created by James Dilley, which they were allowed to examine. The principal investigator then explained verbally that the flake had been removed with a single hard hammer strike by an expert knapper. The test participants were then given protective gloves, goggles and the hammerstone, and given the opportunity to administer several practice blows in order to familiarise themselves with the equipment used. The test participants were allowed to position themselves in a way that they found most comfortable, with the only caveat being that the principal investigator required a clear view of the dial on the scale for recording purposes.

Besides being presented with the core/flake model, no other guidance was given at this stage, either before or during the experiment, regarding the force of blow required to remove the flake from core. Where participants attempted to elicit information from principal investigator as to the required blow strength, an equivocal response was provided to avoid the introduction of bias[56]. Before the recorded blows commenced, particular emphasis was placed on the notion that, in judging what was appropriate in terms of blow strength, the test participants should aim to be as consistent as possible when striking the platform. Test participants where then asked to strike the platform on the top-loading scale a total of 10 times with a blow strength they deemed sufficient to remove a flake as in the model provided. The principal investigator took continuous footage of the 10 percussive blows for later analysis.

After the first 10 blows were recorded, the test participants were asked to administer a further series of 10 blows after receiving guidance from the principal investigator as to the appropriate blow strength required for removing a flake from the core as in the model provided. This was done in two ways: first, the principal investigator advised the participants in general terms as to whether the blows they used were stronger, about the

[56] For example, where one test participant commented that the blow 'would need to be pretty hard', while looking to the principal investigator for confirmation. A neutral reply was provided: 'it's whatever you think would be needed to remove the flake'.

same, or weaker than those required to remove the flake[57]; secondly, a ‘pie slice’ section of coloured card was stuck onto the dial to indicate the range of the ideal strength of blow (i.e., the area where the maximum movement of the needle would need to be when an ideal amount of downward force has been applied) (see Figure 9.5). The test participants were then given a chance to practice applying blows of this kind.

At this point the test participants were reminded that the aim of the training was to reach a stage where they felt they could reliably replicate similar blow strengths a further 10 times. This stage of the experiment was the most challenging in terms of maintaining consistency between test participants and there were notable differences in terms of how much practice each participant required before they felt confident that they could replicate the blow strength required. In all cases, however, the experiment did not continue until the test subject verbally agreed that they felt able to attempt to replicate the desired blow strength.

Following this period of training, the test participants were asked to complete the final series of 10 hammerstone blows on the top-loading scale using a degree of force equivalent to that used in the previous training stage. Again, the principal investigator took continuous footage of the percussive blows for later analysis.

In conjunction with the testing conducted on the above group, a further group of 6 test participants were tested with a procedure that was identical to that outlined above, but with the percussive tasks being introduced in reverse order to ensure randomization. They were asked to read a ‘Participant Information Sheet’ (version 3) containing the necessary

[57] During the initial testing of the equipment it was noted that the approximate movement of the dial can be traced with the naked eye in real time, so feedback was provided by the principal investigator without the need for any analysis of digital recordings.

alterations (see Appendix Figure D) before completing an ‘Informed Consent’ form (version 2) (see Appendix Figure E). Besides reversing the order in which the percussive tasks were introduced, the principal investigator made every effort to ensure the procedure adopted was unchanged.

Finally, on the completion of the experiment, all participants were offered a copy of the relevant Participant Information Sheet, which included the contact details of the principal investigator. For any participants expressing a wish to view the findings of the study, copies will be distributed once the analysis of the results has been completed.

9.3.3. Stage 3: Data Extraction Stage

The data extraction stages involved the analysis of the video footage obtained during the testing stage to extract usable data. Frame-by-frame analysis of the footage was completed in the first instance using Windows Movie Maker, which yielded a maximum of twenty screenshots for each participant (i.e., 10 blows applied according to the test participant’s judgement and 10 blows applied with guidance of principal investigator). These screenshots were subsequently edited using Microsoft Paint to add a ‘Red Line’ to the images to help highlight the maximum extent of the needle’s passage (see Figure 9.6).

Figure 9.6: Example of an edited screenshot with a red line added to provide a visual aid for taking readings from the dial of the top-loading scale.

Using the red-lined images for reference, readings were then taken directly from the dial on the top-loading scale by placing a standard 30cm ruler at the appropriate point. This process yielded a reading in grams, rounded to the nearest 20 gram marker. Finally, the data were adjusted to account for the starting position of the needle. Due to the removal of various heavy metal parts from the top-loading scale prior to use, the needle was in a permanent position of -780g that could not be adjusted. All data points therefore needed an addition of 780 to achieve a true reading in grams.

9.4. Qualitative Data Collection: 2nd Phase

A second phase of qualitative research was undertaken in response to a perceived need to understand the quantitative results more fully (Creswell & Plano Clark, 2011: 119). The adoption of this mixed methods approach was emergent rather than fixed in nature, developing as a result of issues that arose while the quantitative research was being conducted (Creswell & Plano Clark, 2011: 54). Specifically, the issues that arose concerned:

1) The body position adopted by the test subjects, the way the test subjects held the core and hammerstone, and the characteristics of the blows they applied
2) The influence of self-learning within the context of the experimental design from the first phase (i.e., two short sequences of 10 blows over a time period of no more than five minutes)

Regarding the former, this second strand of research was prompted by informal observations by the principal investigator during quantitative data collection in the first phase. The principal investigator noted that the majority of test participants (nine of the twelve who participated) tried out several body positions around the scale, sometimes attempting dummy blows, before settling on the most comfortable position. Indeed, informal field notes from the first phase recorded after the completion of the task noted two of the test subjects reporting the 'unnatural' and 'awkward' body position needed to strike the top of the scale. A qualitative assessment of the body positions, hammerstone/core grips, and blow characteristics adopted by test subjects in a setting more comparable to a typical knapping environment was therefore deemed necessary.

Regarding the latter, the adoption of randomisation in the quantitative phase raised interesting points regarding self-learning in a knapping task. The intent of randomisation was to ensure that the order in which the tasks were introduced did not bias how test subjects performed in the respective conditions. If, for example, all the test subjects in the first phase administered 10 blows under their own judgement followed by 10 blows after training, it remains a possibility that any increase in consistency in the latter may be a result of increased familiarity with the task, possibly as a result of the earliest stages of self-learning.

Another area considered worthy of exploration, therefore, was to examine whether test subjects exhibited a capacity for self-learning within the kinds of short periods of exposure used in the first phase (i.e., approximately 5 minutes of activity applying a total of twenty blows). In particular, the aim was to assess whether viewing video footage of an expert knapper prompted changes in the attitudes and behaviour of the test participants regarding not only body positions, hammerstone grip and core grip, but also the height from which the blows were delivered and the degree of lateral movement exhibited when delivering the blows.

9.4.1. Research Design

The research design adopted was an emergent explanatory sequential design (Creswell & Plano Clark, 2011: 104). It is explanatory in that it consisted of two distinct phases: a primary quantitative phase followed by a qualitative phase that was added in order to answer new questions that could not be addressed via quantitative data alone (Creswell & Plano Clark, 2011: 82). It can be considered emergent in that the incorporation of a second qualitative phase was only deemed necessary after quantitative data gathering had commenced and was prompted by observations made during that process (no part of the qualitative phase, therefore, was designed prior to the quantitative data gathering) (Creswell & Plano Clark, 2011: 54).

An explanatory sequential design was deemed ideal for research purposes in this instance for the following reasons: explanatory sequential designs are well suited to research that begins with a strong quantitative orientation; the two-phase structure of an explanatory sequential design is easy to implement; explanatory sequential designs are amenable to research conducted by individual researchers, as opposed to a research team, due to the respective phases being conducted sequentially (Creswell & Plano Clark, 2011: 83).

9.4.2. Participants

James Dilley was an initial participant in the testing process. He produced the core/flake model task for the first phase of testing, which was also utilised in the second phase. Video footage of James reducing a core to produce the model core/flake was also utilised in the test design (see procedure section below).

A total of 12 individuals participated in the data collection process (see Table 9.2). As noted by Creswell and Plano Clark, when utilising an explanatory sequential design to examine quantitative results more deeply one should ideally include the individuals who contributed to the original data set (2011: 185). This was possible for 10 of the 12 participants who contributed to the first phase, with 2 participants being unavailable for further participation (Subject 1 and Subject 5).

Subject	Age	Gender	Occupation
Subject 2	39	Female	Lecturer (Forensics)
Subject 3	69	Male	Retired - plastic fabricator
Subject 4	64	Female	Retired – accounts worker
Subject 6	29	Male	Student (structural engineering)
Subject 7	21	Male	Administrative worker
Subject 8	32	Female	Student liaison worker
Subject 9	28	Female	Engineer (working area not related to fracture of brittle solids)
Subject 10	23	Male	IT technician
Subject 11	39	Male	Administrative worker
Subject 12	70	Male	Planning consultant
Subject 13	31	Female	Student (health psychology)
Subject 14	44	Male	IT Technician

Table 9.2: Demographic data for the 12 participants who contributed to the qualitative testing in the second phase (note that Subject 1 and 2 from the first phase were replaced with Subject 13 and Subject 14 in the second phase).

Of the test subjects that contributed to the quantitative stage, 6 male and 4 female participants participated in qualitative data gathering, with ages ranging from 21 to 70. Two other test participants who had not contributed to the quantitative data gathering also agreed to participate (1 male (44), 1 female (31)). These test subjects are referred to below as test subject 13 and test subject 14 to prevent possible confusion with the test participants who were unavailable for the second phase of testing. For all other participants the test subject number from the first phase has been retained in the second phase.

For the 12 test participants the mean age was 41 years with a standard deviation of 17.55. All participants were drawn from existing acquaintances (friends, family and work colleagues) of the principal investigator. The professions covered by the test participants were: planning consultant (1), university lecturer (1) (Forensics), IT technician (2), administrative worker (2), student liaison worker (1), engineer (working area not related to fracture of brittle solids) (1), students (2) (studying structural engineering and psychology), retiree (2) (former professions were accounting and plastic fabrication).

No test participants reported previous experience of knapping. No inducements were offered to any members of the sample for their participation. Anonymity was ensured for all test participants as per the University of Durham's Ethics policy in accordance with the principles of the Data Protection Act (1998), and the data were retained only for the stated purpose of testing (i.e, to extract the required data from the video footage). Subject 11, however, verbally agreed to waive his anonymity for the purposes of illustrating the testing procedure; screen captures of his participation are therefore included in the appendices.

9.4.3. Apparatus and Materials

The following apparatus and materials were employed within the experiment design. A wooden substitute core with dimensions 19.4cm x 9.8cm x 7.4cm with a 'flake' removed as an example prior to testing (see Figure 9.7). The large, ovoid, quartzite hammerstone from the first phase was used by test participants to strike the substitute core (see Figure 9.3). Again, the hammerstone weighed 780g, consistent with previous experimental work utilising hammerstones in flint knapping experiments (Bril, et al., 2010: 4; Dapena, et al., 2006: 334; Geribàs, et al., 2010: 2859; Newcomer, 1971: 85) and within the weight range

Figure 9.7: The wooden substitute core (19.4cm x 9.8cm x 7.4cm) used by participants in the second phase. An example flake was removed prior to testing (bottom left) and test participants were asked to apply blows to remove a similar flake on the adjacent corner (top right, with a black dot indicating the approximate striking point) (scale in cm).

typically employed for removing the larger flakes associated with the initial roughing-out phase of preparing a biface blank (James Dilley - *Pers. Comm.*). To give test participants a feel for the raw material used in knapping, the model flint core/flake produced for the first phase by expert knapper James Dilley (see Figure 9.4) was made available for examination.

A card backdrop was used during testing that containing both a vertical and horizontal scale in centimetres (see Figure 9.8). On adopting a body position deemed comfortable for

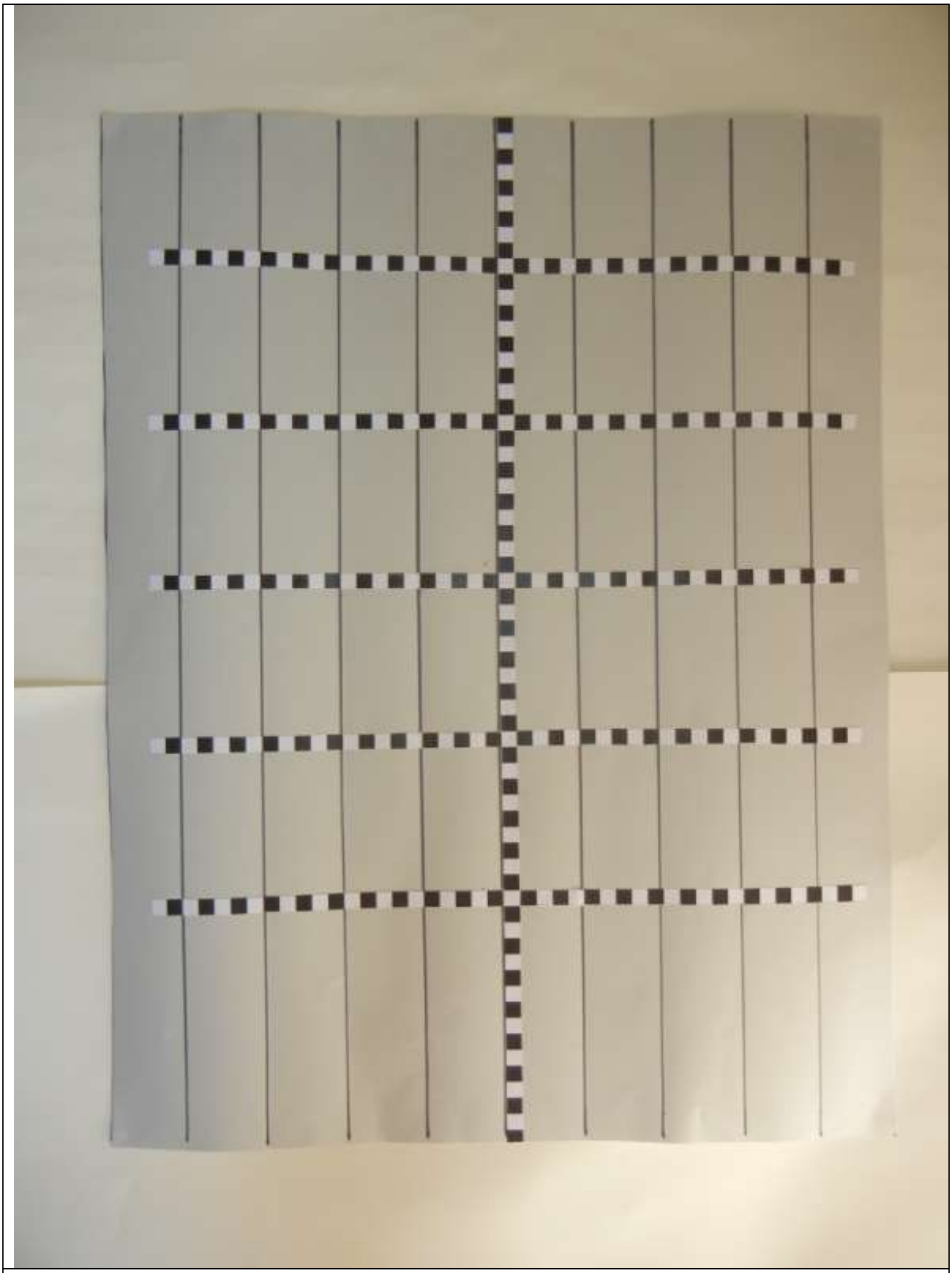


Figure 9.8: The card backdrop was used during testing with vertical and horizontal scales in centimetres (plus vertical lines at 5cm intervals). For testing this backdrop was affixed to a hard surface and positioned behind each of the test participants to allow the height to which the hammerstone was raised and the degree of curvature in the swing to be recorded.

the knapping task, the backdrop was positioned behind the test participant to allow the degree of vertical movement in the hammerstone and curvature in the swing to be recorded. Vertical parallel lines at 5cm intervals were also included on the backdrop to assist the data extraction stage by ensuring that all 'red lines' added for the purposes of taking measurements during the screenshot editing process remained parallel.

Footage of the percussive episodes was filmed using the video function on a Nikkon Coolpix S1800 digital camera for subsequent analysis. A short film (44 seconds long) showing James Dilley applying a total of six hard hammerstone blows to a core was also used to show to test participants. This footage showed his full body posture, as well as his hammerstone grip and hammerstone swing. Finally, test participants were also provided with a pair of heavy duty gloves and protective goggles.

9.5. Testing Procedure

Data were collected from test participants under two conditions: when adopting a knapping position according to their own preference and when adopting a knapping position after viewing footage of an expert knapper reducing a core (referred to as 'after instruction' hereafter). Prior to testing each test participant was asked to read the Participant Information Sheet (Version 4) and invited to complete an Informed Consent form (Version 3) (see Appendix Figures F and Appendix G). Testing only proceeded past this point once the test participants had verbally agreed that they understood what the task entailed, had the chance to ask any questions, and were informed that they were free to leave the session at any time.

Before the experiment commenced, the main points of the participant information sheet were reiterated verbally to the test participants; i.e., that it involves a percussive task with two stages, each requiring enacting a series of 10 hammerstone blows. The procedure employed during testing can be broadly delineated into two stages: the testing stage, and the data extraction stage.

9.5.1. Stage 1: Testing Stage

Testing involved 12 participants with no experience of flint knapping completing percussive tasks. Participants took part in the experiment individually. Again, where it was necessary for several participants to be tested consecutively (e.g., when several subjects were available for testing at once, but within a limited time frame), each participant was tested in isolation and no conferring was allowed between individuals who had participated and those still waiting to do so. Randomization was deemed unworkable due to the fact that the test design examines before/after conditions that cannot be reversed (i.e., if a test participant is introduced to the video footage initially, it would be impossible to collect data on how they would interpret the task using only their own judgement).

Each of the 12 test participants was first presented with the model consisting of a single flint flake removal (see Figure 9.4) and the ovoid hammerstone (see Figure 9.3), and asked to reflect on what degree of force would be needed to remove the flake with the hammerstone provided. Test participants were then introduced to the substitute core and flake (see Figure 9.7) and verbally informed of the test procedure for applying 10 blows to the substitute core.

The use of standardized instructions, a recommended practice in designing/reporting methods in psychology (Harris, 2008: 43), was adopted at this stage to minimise the introduction of bias as a result of differing style, content, or delivery of instruction on the part of the principal investigator. The instructions used were as follows:

> In a moment I will ask you to adopt a comfortable position for hitting the substitute wooden core with the hammerstone provided. I would like you to hit the wooden block 10 times as close as possible to the black dot on the surface, as if you were attempting to remove a flake similar to that already detached from the wooden block [*principal investigator shows test participant black dot and wooden flake if needed*]. When applying the 10 blows, however, I would like you to use a blow strength identical to that which you think would remove the flint flake from its core as in the model viewed previously [*principal investigator shows test participant flint flake/core again*].
>
> In sum, I would like you to strike the substitute core at the point of the black dot with a blow strength you feel is hard enough to detach the flint flake from its core. I would like you to adopt a position you feel most comfortable for the task.

When completing the task the data relating to the body position, the method of securing the core in the non-dominant hand, and the hammerstone grip with the dominant hand were recorded. Field notes were also taken of any relevant comments made by the test participants relating to the task. Prior to the test commencing the principal investigator positioned the backdrop with horizontal and vertical scales behind the test participant, and the 10 hammerstone blows were filmed to allow data extraction at a later stage (see data extraction stage below). All video footage was taken from a height of approximately 70cm from the floor, at a distance of approximately 80cm from the backdrop, and with the core the same approximate distance from the backdrop to reduce the risk of differing perspectives distorting the data extracted from the resulting footage.

The test participants were then shown a short film (44 seconds long) showing James Dilley applying a total of six hard hammer blows to reduce a core. The test participants were asked to reflect on their knapping technique before being shown the footage, and were then asked to apply a further 10 blows to the substitute core while incorporating any adjustments (or none if they preferred) to their technique. Again, standard instructions were used for all 12 participants:

> Please now reflect on some aspects of your knapping technique: how you sat, how you held the core and the hammerstone, how hard you struck and how straight or curved your swing was) [*allow 10-20 seconds to reflect*]. With these factors still in mind, I would like you to view footage of an expert knapper making the flint flake/core model [*principal investigator shows test participant the footage of James Dilley*]. I would now like you to perform 10 more hammerstone blows, again aiming at the black dot on the substitute core, but with any adjustments made to your technique (or none, if you prefer) that you feel would improve your performance.

Again, data relating to the body position, the method of securing the core in the non-dominant hand, and the hammerstone grip with the dominant hand were recorded in real time and the 10 blows were filmed with the backdrop behind the test participant to allow further data extraction at a later stage. Field notes were also taken of any comments made relating to the task.

Finally, on the completion of the experiment, all participants were offered a copy of the relevant Participant Information Sheet, which included the contact details of the principal investigator. For any participants expressing a wish to view the findings of the study, copies will be distributed once the analysis of the results has been completed.

9.5.2. Stage 2: Data Extraction Stage

The data extraction stage involved collating data from both written field notes and filmed footage. From the written notes data were collected for body position, core position and hammerstone grip. The test participants used a total of five body positions: squatting, kneeling (both knees), kneeling (one knee), sitting (legs outstretched), sitting (cross legged), (see Figure 9.9). The test participants used a total of five core grips: three of these were freehand (i.e., not supported on the body or the ground) in nature, and were gripped underneath the core (bottom grip), at the side of the core (side grip) or at the short end of the core (end grip). The other two core grip positions were resting on the thigh and secured on the ground (see Figure 9.10). The test participants used a total of four hammerstone grips: claw grip, side grip, three-fingered grip, spread-fingered grip (see Figure 9.11). Analysis of the video footage obtained during the testing stage allowed the extraction of data relating to the maximum height of the hammerstone for each blow and the degree of lateral movement of hammerstone between highest point and point of impact on the core

Frame-by-frame analysis of the footage was completed using Windows Movie Maker. For each hammerstone blow the frame showing the maximum height of the hammerstone was first isolated. These screenshots were subsequently edited using Microsoft Paint to add a 'red line' to highlight the maximum height of the hammerstone and the position of striking platform (see Figure 9.12). A blue line was added to highlight the start position for measuring the degree of lateral movement - the outside edge of the hammerstone furthest away from the test participant was used as a reference point (see Figure 9.12).

Figure 9.9: The 5 body positions used by the 12 test participants. Squatting (top left); kneeling, both knees (top right); kneeling, one knee (middle left); sitting, legs outstretched (middle right).sitting cross legged (bottom left).

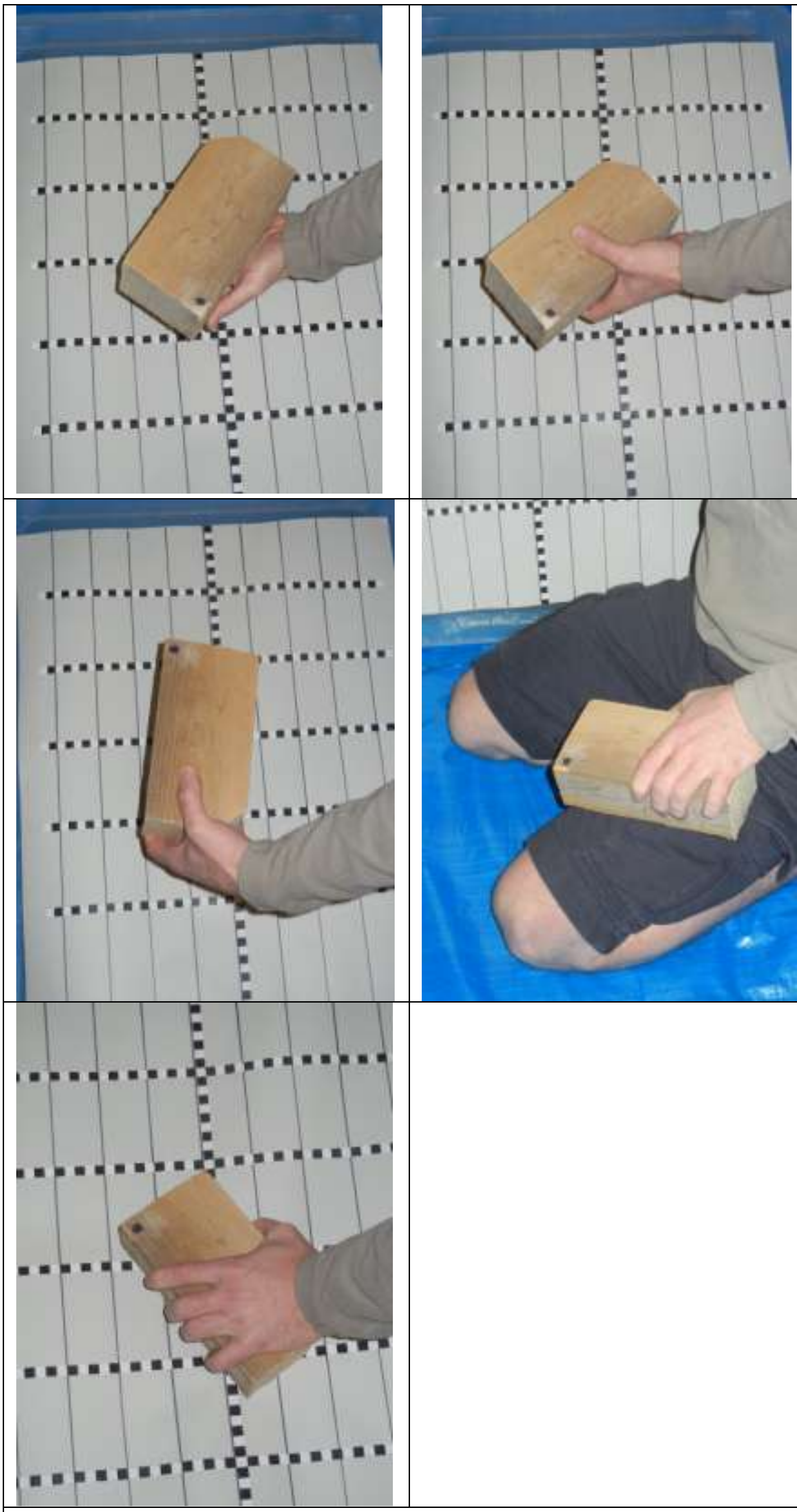


Figure 9.10: The five core grips used by the test participants. Freehand, bottom grip (top left); freehand, side grip (top right); freehand, end grip (middle left); resting on thigh (middle right); secured on ground (bottom right).

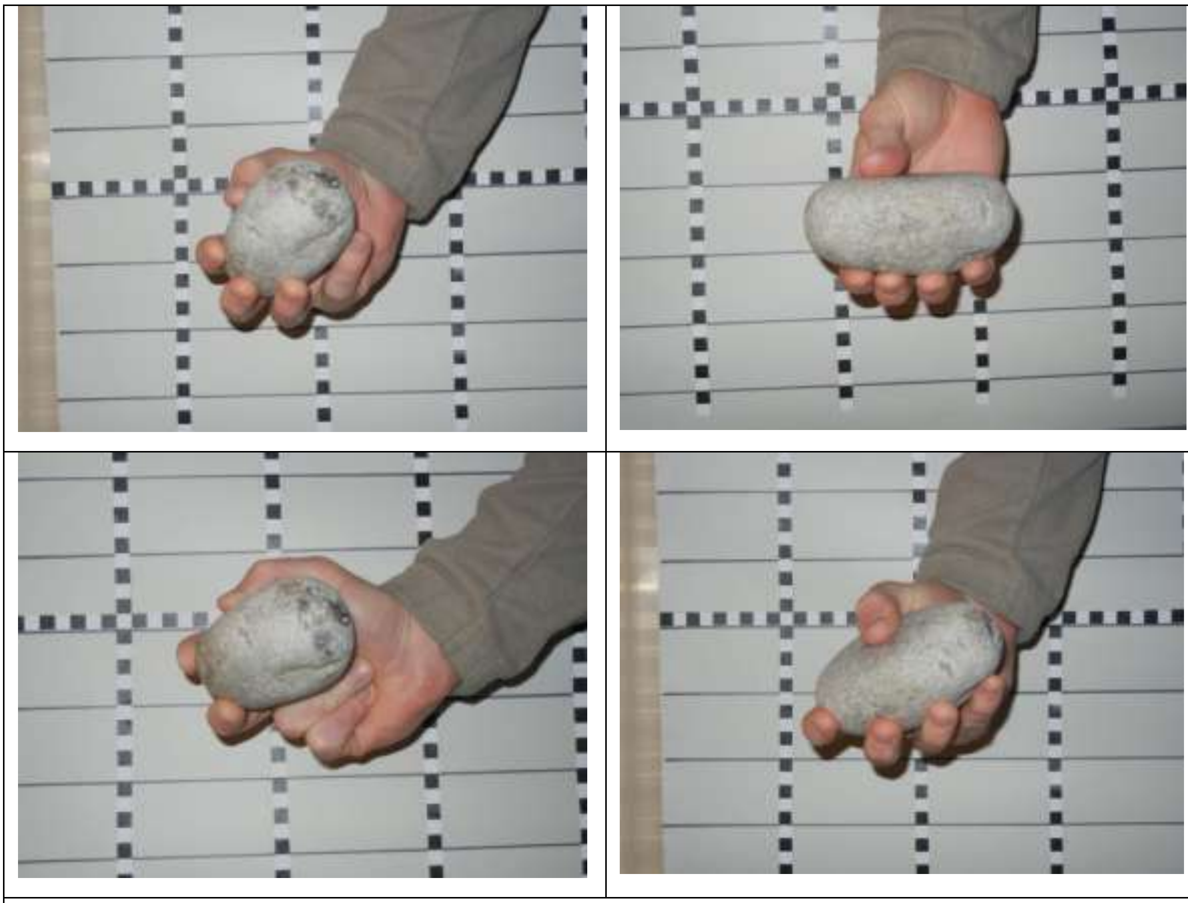


Figure 9.11: The four hammerstone grips used by test participants. Claw grip (top left), side grip (top right), three-fingered grip (bottom left), spread-fingered grip (bottom right).

The height of the hammerstone could be read directly from the vertical centimetre scale at this stage. To establish the degree of horizontal movement, measurements were taken of the centimetre difference between the blue lines from two screenshots: a screenshot recording the outside edge of the hammerstone at its starting position and a screenshot recording the outside edge at the position where it exhibited the maximum degree of lateral movement (see Figure 9.12). For some test participants the body position adopted resulted in parts of the scale being obscured. Similarly, for some participants the height of the hammerstone blow extended beyond the scope of the scale. In such instances the scale was replaced over the obscuring body part or extended beyond the scope of the original scale by editing the picture to allow measurements to be taken (see Figure 9.13).

Figure 9.12: Examples of edited screenshots from the footage obtained from Subject 11. The coloured lines were added to provide a visual aid for taking readings from the vertical and horizontal scales during the data extraction stage. The height of the hammerstone blow (i.e., the distance between the two red lines) can be determined from the image showing the maximum height of the hammerstone and the position of the striking platform (left). Note that though the red line at the bottom is not lined up with the scale, the scale can be extended in the editing process to allow readings to take place (see Figure 9.13 below). The degree of lateral movement of the hammerstone blow can be established by comparing the degree of movement from the outside edge of the hammerstone in its starting position (blue line in the image on the left) with the point of its maximum horizontal movement (blue line in the image on the right).

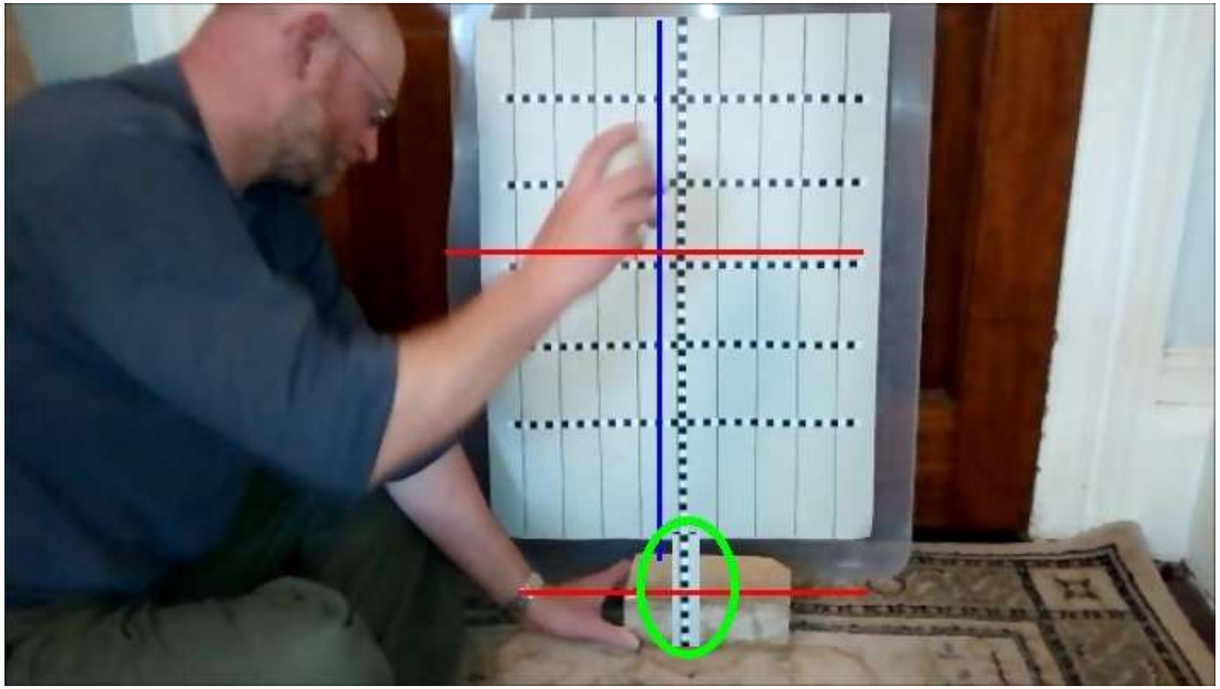


Figure 9.13: Example of an edited screenshot with an extended scale from the footage obtained from Subject 11. Though the board with the centimetre scale was well suited for recording most movements, some test participants adopted positions that necessarily went beyond the limits of the scale. In this example the test subject chose to place the core on the floor which hindered measurement of the distance between the two red lines. This problem was remedied during editing by copying and pasting sections of the scale to extend its scope, thereby allowing measurements to be taken. The section of scale circled in green, for example, is not present in the original screenshots (compare to Figure 9.12, left hand image, which does not have a scale extension added). The same method was used in instances where the scale was partly obscured by the body of a test participant.

9.6. Conclusion

In conclusion, this chapter outlined the mixed methods, explanatory sequential design that was employed to gather data relating to various aspects of novice performance in a knapping task.

The first phase aimed to collected data relating to the judgement of blow strength by novice knappers. This phase was quantitative in nature and designed according to the methodology of Evolutionary Psychology. Details of the research design, the demographics of participants, the apparatus and materials used, and the procedure employed were described in full.

As noted above, the test procedure was designed to gather data relating to the judgment of blow strength by novice knappers in a knapping task in two differing conditions: one that was consistent with the conditions reliably encountered in past environments (EEA conditions), and those that deviate from EEA conditions. The proposed hypothesis that the test designed aimed to examine is that test participants would display better judgement (determinable through greater consistency) when applying blow strengths consistent with those utilised in EEA conditions when compared to blow strengths that seem intuitively appropriate. The null hypothesis was that no notable difference would be apparent in the degree of consistency displayed by the test participants in the respective conditions.

The second phase of qualitative data collection was undertaken as a result of issues that arose during quantitative data collection. Specifically, it was noted that test participants tried various body positions in response to the apparatus used. An examination of how test subjects viewed various aspects of the task (i.e., body position adopted, the way the core and hammerstone are held, and the way blows are applied) in the absence of the perceived constraints introduced by the apparatus utilised in the first phase was therefore deemed necessary.

The potential influence of self-learning for novices in the earliest stages of knapping skill development was also examined, particularly with a view to exploring whether such factors could provide further insight into the quantitative results. Data collection in the second phase was in agreement with the general rationale for adopting a mixed methods approach, with the quantitative data taking priority for answering the main questions of the study, and subsequent qualitative data collection being employed to ‘refine and explain […] statistical results by exploring participants views in more depth’ (Creswell & Plano Clark, 2011: 71, 104).

Chapter 10: Mixed Methods Research Design Results

10.1. Introduction

The purpose of this chapter is to present the data collected in the quantitative and qualitative phases in accordance with the methodology described in Chapter 9. A mixed methods, explanatory sequential design was employed where quantitative data had precedence in answering the main research questions, while the qualitative data provided further insight into various aspects of the quantitative results (Creswell & Plano Clark, 2011: 71).

The quantitative phase employed a 'one group pre test/post test design' (Field & Hole, 2006: 68). The overall aim of the design was to compare the degree of consistency (the outcome variable) exhibited by the test subjects when applying blows in two conditions: i.e., where the test subjects apply blows they deem appropriate for the task using their own judgement and where the test subjects apply blows after training that provides guidance as to the appropriate blow strength for the task presented. The appropriate blow strength for the given task (as defined by an expert knapper) represented the independent variable and was manipulated on two levels (present or absent) (Field & Hole, 2006: 21; Harris, 2008: 128). The independent variable was deemed to be present when test participants were applying blows appropriate for the task (as defined by the expert knapper), and absent when they applied blows in conditions that deviated from it (according to their own judgement).

The design aimed to examine a one-tailed (directional) hypothesis (Field & Hole, 2006: 155; Harris, 2008: 137) that test participants will display better judgement (determinable through greater consistency) when applying blow strengths that are equivalent to those typically encountered in a knapping task, as opposed to those blow strengths that seem intuitively appropriate. The null hypothesis is that there no difference will be discernible between the two data sets.

The subsequent qualitative phase of data collection was undertaken to further examine two issues that arose during the quantitative phase. First and foremost, the intention was to assess test subjects interpretation of appropriate body position, core grip, hammerstone grip and blow height/trajectory in the absence of the measuring equipment used in the first phase. This part of the qualitative phase was prompted by concerns that the apparatus utilised in the first phase may have impeded the test subjects' blow application in various ways.

Secondly, the qualitative phase aimed to explore whether self-learning was evident for novices in the earliest stages of knapping skill development. Here, the aim was to clarify whether self-learning influenced test participants' behaviour during the short testing episodes used in the first phase. This, in turn, could inform the study as to whether self-learning could have influenced the degree of consistency exhibited in the first phase by test participants.

10.2. The Quantitative Data

The raw data consist of a series of 10 data points provided by James Dilley and 20 data points for each of the 12 test subjects (i.e., 10 blows stemming from their own judgement of the required blows strength for the defined task, and 10 blows applied after training was provided). Due to isolated problems encountered during testing there are 2 missing data points: one pertaining to Subject 2 (blow 10, own judgment) and one for Subject 7 (blow 4, own judgement).

Table 10.1 presents the raw data collected as per the methodology outlined above, while Table 10.2 presents the descriptive statistics. The following descriptive statistics will be provided as measures of central tendency (Harris, 2008: 49).

- The Mean (i.e., the sum of all scores divided by the number of scores)
- The Median (i.e., the middle score within a distribution of data)

In addition, the following descriptive statistics will be provided as measures of variation/dispersion (Harris, 2008: 49).

- The Standard Deviation
- The Range: (i.e., the difference between the highest and lowest scores)

As per the methodology outlined above, the key areas to examine for the descriptive statistics are those concerned with variance. Measures of central tendency will also be discussed below, but only to establish: a) whether the mean blow strength for the test participants was more forceful than those applied after training, as assumed in the methodology, and b) whether the data for a given subject has outliers that are skewing the results of the mean.

Blow Number	Blows Administered According to Own Judgement												
	Subject 1	Subject 2	Subject 3	Subject 4	Subject 5	Subject 6	Subject 7	Subject 8	Subject 9	Subject 10	Subject 11	Subject 12	Knapper
1	6180	7160	2140	7400	3960	2960	4580	10400	680	10760	2380	8920	2300
2	7160	8480	1220	4980	4700	8400	5660	10360	960	9800	5980	8780	2520
3	6800	8520	2140	4740	5640	8380	4280	9860	1660	10440	7340	9280	2140
4	6960	9400	2500	2200	5240	7440		10080	1900	9340	5320	8860	1940
5	6800	9100	1940	1880	5260	7800	4640	9980	2140	9500	5880	8520	2220
6	6220	9460	1820	3840	5080	2500	6920	9520	2040	8740	4880	8360	2220
7	6320	9480	1300	4100	4660	3380	6700	8500	2380	9140	6580	8140	2080
8	6220	8760	1080	4200	4860	1740	7880	2320	2780	8420	5780	8760	2640
9	6460	8380	1260	4180	4060	2060	7900	4700	2620	8600	8040	8600	1840
10	6040		1200	4300	4520	3320	7800	2140	3100	8020	8040	8460	2020

Blow Number	Blows Administered After Training											
	Subject 1	Subject 2	Subject 3	Subject 4	Subject 5	Subject 6	Subject 7	Subject 8	Subject 9	Subject 10	Subject 11	Subject 12
1	3500	5220	2360	2480	1920	5220	5140	6300	3500	5580	4320	3760
2	780	7980	1680	4580	2520	4760	4760	5680	5340	6120	1920	4420
3	900	6980	2500	4320	2600	6040	5580	5460	4640	6920	1820	4220
4	840	6400	2000	6300	2540	4420	5880	7060	3980	8060	1440	3640
5	1820	7020	2160	4720	2760	4860	5660	5400	4800	7480	1040	2720
6	1480	6640	1880	1640	2680	4860	5080	6640	4480	8300	4280	2500
7	1380	7860	2460	1560	2100	4500	5300	4660	4140	9380	2160	2080
8	1360	7300	2020	2920	2200	5200	4840	4900	4080	8780	1840	5100
9	1360	7580	1680	1600	2640	5280	5080	6280	4340	9180	2860	2780
10	1520	6560	2640	4280	2940	5320	4820	4860	4420	8640	1360	1920

Table 10.1: The raw data collected for the 12 subjects in the Quantitative Phase. For each subject a series of 10 blows were recorded in two different conditions; when using their own judgement (top) and when attempting to use appropriate blow strengths for the task after training (bottom). All values are in grams, rounded to the nearest 20g marker on the scale, and are adjusted to account for the initial -780g setting on the scale. The blows strengths provided by the exert knapper are included with the blow strengths applied according to the subject's own judgement (top, far right).

	Descriptive Statistics from Blows Administered According to Own Judgement												
	Subject 1	Subject 2	Subject 3	Subject 4	Subject 5	Subject 6	Subject 7	Subject 8	Subject 9	Subject 10	Subject 11	Subject 12	Dilley
Mean	6516	8749	1660	4182	4798	4798	6262	7786	2026	9276	6022	8668	2192
Standard Deviation	384	739	506	1516	533	2819	1502	3377	768	879	1678	323	248
Median	6390	8760	1560	4190	4780	3350	6700	9690	2090	9240	5930	8680	2180
Range	1120	2320	1420	5520	1680	6660	3620	8260	2420	2740	5660	1140	800
Interquartile Range	580	970	920	900	720	5300	3190	5380	960	1200	2020	400	280
Standard Error	122	246	160	479	169	891	501	1068	243	278	531	102	78
Co-efficient of Variation	0.06	0.09	0.31	0.36	0.11	0.59	0.24	0.43	0.38	0.1	0.28	0.04	0.11
Relative Standard Deviation	6%	9%	31%	36%	11%	59%	24%	43%	38%	10%	28%	4%	11%

	Descriptive Statistics from Blows Administered After Training											
	Subject 1	Subject 2	Subject 3	Subject 4	Subject 5	Subject 6	Subject 7	Subject 8	Subject 9	Subject 10	Subject 11	Subject 12
Mean	1494	6954	2138	3440	2490	5046	5214	5724	4372	7844	2304	3314
Standard Deviation	780	814	343	1631	318	473	384	816	501	1291	1161	1070
Median	1370	7000	2090	3600	2570	5030	5110	5570	4380	8180	1880	3210
Range	2720	2760	960	4740	1020	1620	1120	2400	1840	3800	3280	3180
Interquartile Range	620	1020	580	2940	480	520	740	1400	560	1860	1420	1720
Standard Error	247	257	108	516	101	150	121	258	158	408	367	338
Co-efficient of Variation	0.52	0.11	0.16	0.47	0.13	0.94	0.74	0.14	0.12	0.17	0.5	0.32
Relative Standard Deviation	52%	11%	16%	47%	13%	9%	7%	14%	12%	17%	50%	32%

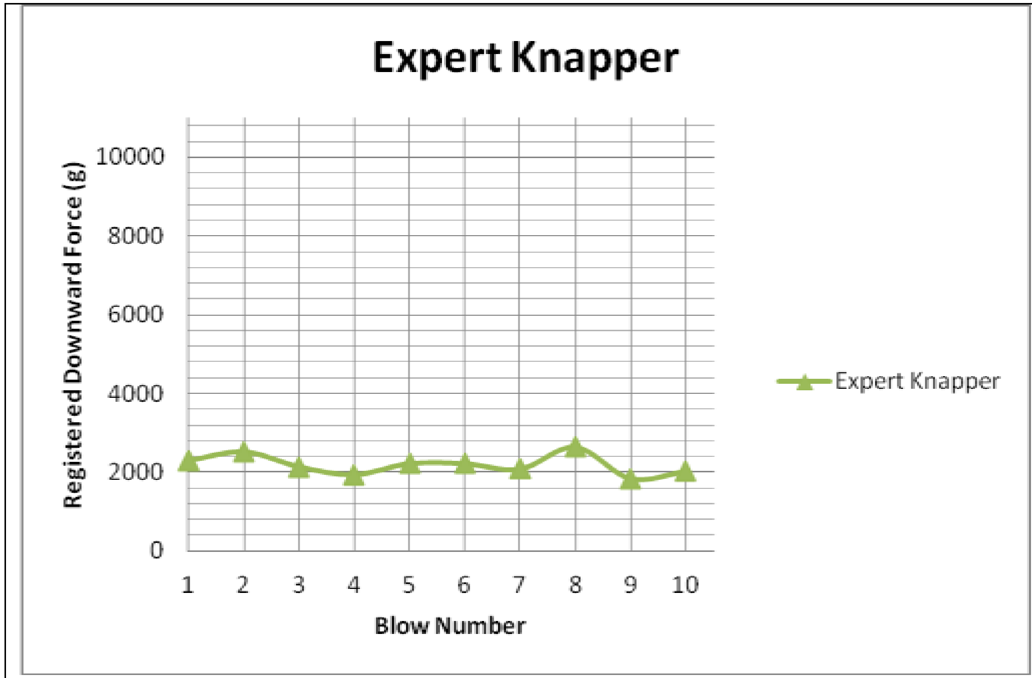
Table 10.2: The descriptive statistics calculated for the 12 subjects from the raw data in the Quantitative Phase. When using their own judgement (*top*) and when attempting to use appropriate blow strengths for the task after training (*bottom*). For each subject the mean and median are presented as measures of central tendency, while the standard deviation, the range, the interquartile range, the standard error, the co-efficient of variation and the relative standard deviation are presented as measures of variance. All values relate to the values in grams as with the raw data. The descriptive statistics relating to the exert knapper are included in the 'own judgement' table (*top, far right*).

10.2.1. The Expert Knapper

As well as providing data to establish the ideal blow strength for the model task presented to the test participants, the blows recorded by James Dilley also indicate what one can reasonably expect from the test participants in terms of measures of central tendency and variance.

Regarding the comparison between the mean and median scores, James produced a mean blow strength of 2192g with a median score of 2180g (see Figure 10.1). Both the composite image and the range for James' data (all blows fell within a range of 800g) show a high level of consistency was achieved in his application of blows.

Regarding the measure of variance, James achieved a standard deviation of 248. Since it would be unreasonable to expect novice knappers to perform better than an expert with 10 years' experience, we can therefore use James Dilley's standard deviation as an ideal target score for dispersion.



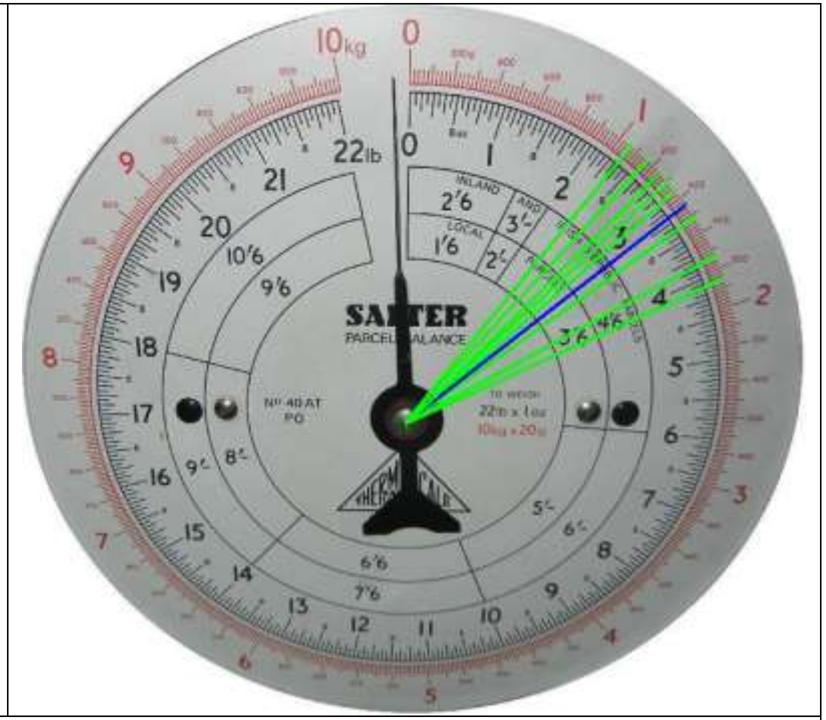


Figure 10.1: Data for the 10 blows recorded by expert knapper James Dilley when re-enacting the blow strength used to remove the flake from the model core. *Top Left*: Line graph displaying the 10 blows (data adjusted to account for negative measure of 780g on the scale). *Top Right*: Composite image of the dial face of the scale with each of the 10 blows depicted (green lines represent single blows, while the blue line depicts two single blows that fell in the same place). *Bottom:* the tabulated raw data, together with measures of central tendency and dispersion (i.e., mean, standard deviation, median, and range).

10.2.2. Subject 1

As anticipated, when using his own judgement Subject 1 overestimated the required blow strength, and successfully adjusted the blow strengths applied after training to within the desired range. Figure 10.2 charts the ten blows applied by Subject 1 in the two sets of conditions alongside those of James Dilley.

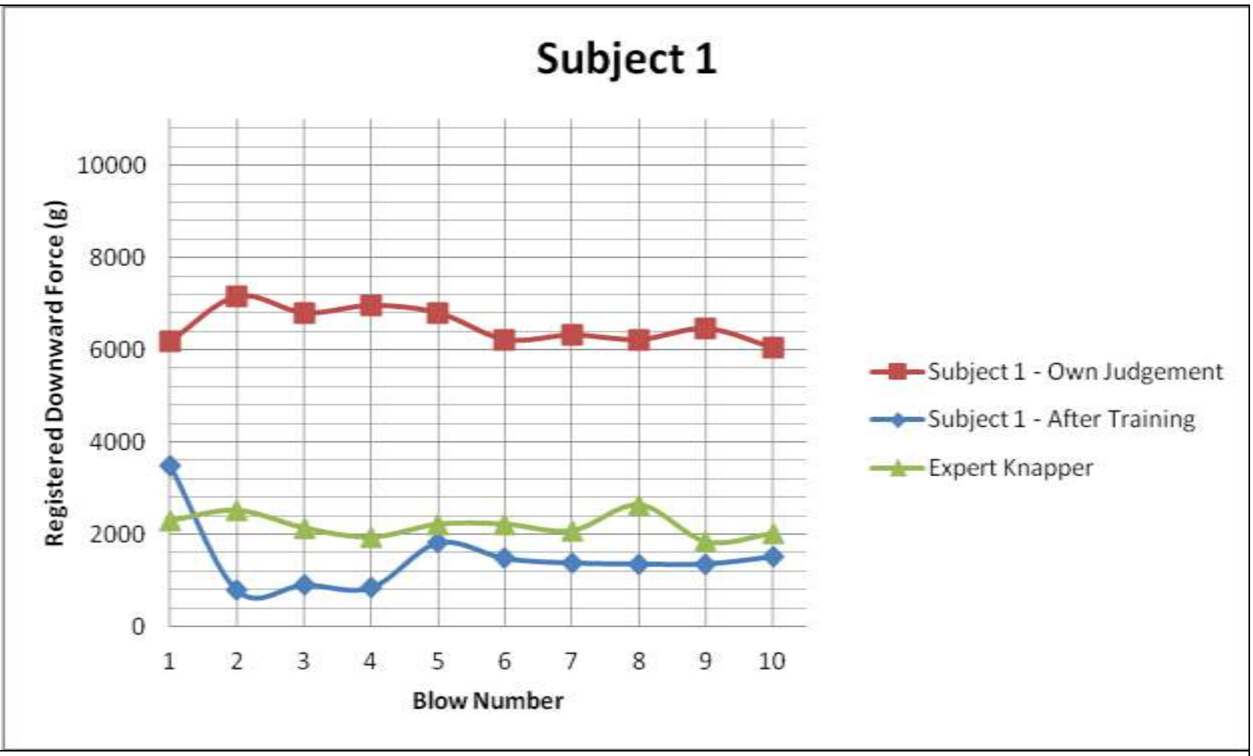
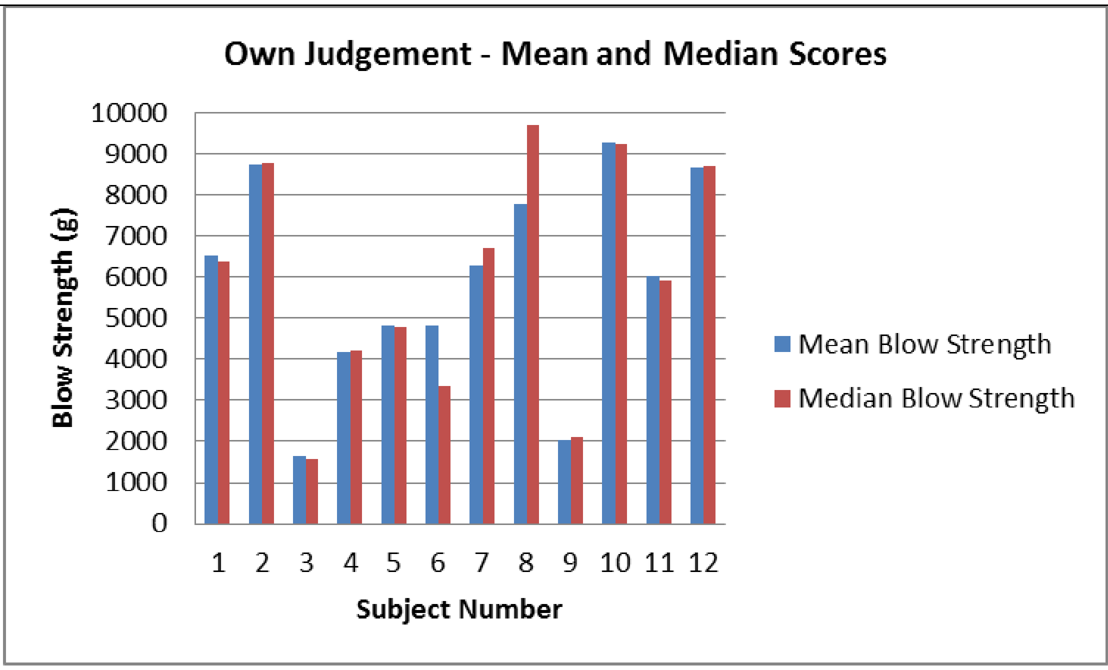


Figure 10.2: Line graph showing blows applied according to test Subject 1's own judgement (red), blows applied after a period of training (blue) and those applied by the expert knapper (green).

A. Measure of Central Tendency

Subject 1 showed a high level of consistency in both data sets. Using his own judgement he registered a mean blow strength of 6516 and a median of 6390, while after training he registered a mean blow strength of 1494 and a median of 1370 (see Figure 10.3).



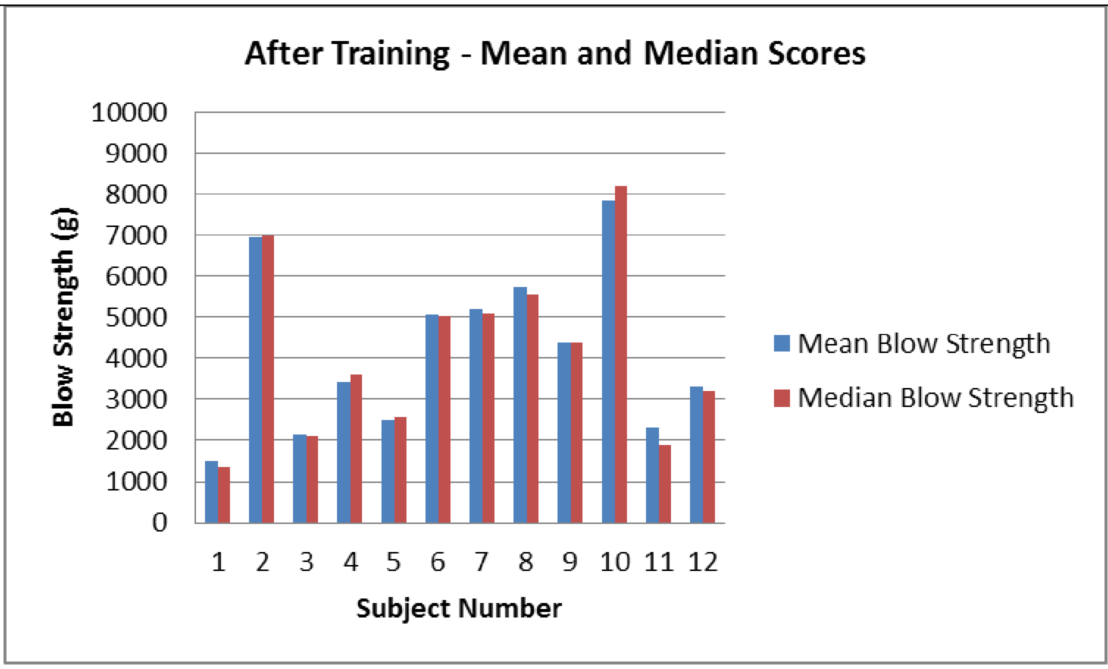


Figure 10.3: Comparison of Mean and Median blow strength scores for the 12 test participants when using their own judgement (*left*) and after training (*right*).

The range of the data recorded for Subject 1 when using his own judgement also suggests a good level of consistency, with a range of 1120. In contrast, the data range recorded for Subject 1 after training suggests outliers may be present in the data, as indicated by a higher range of 2720. The composite image of registered blows appears to support this, with 1 blow being noticeably more forceful than the others (see Figure 10.4).

B. Measure of Variance

In terms of variance, the data provided by Subject 1 appears to exhibit a trend that was opposite to that hypothesised: i.e., less variance when using his own judgement (as indicated by a standard deviation of 384, which is comparable to James Dilley's score of 248) and a higher degree of variance after a period of training as indicated by the standard deviation of 780 (see Figure 10.5). This latter figure may be skewed by the influence of the outlier mentioned previously. If the score for the outlier (3500g of downward force registered in blow 1 after training) is removed from the dataset the remaining 9 blows recorded yield a standard deviation of 353. Though this single outlier may account for the higher standard deviation for the blows applied after training, the two standard deviation scores remain very similar even if it is disregarded. A significant increase in consistency is therefore not evident for Subject 1 after the period of training.

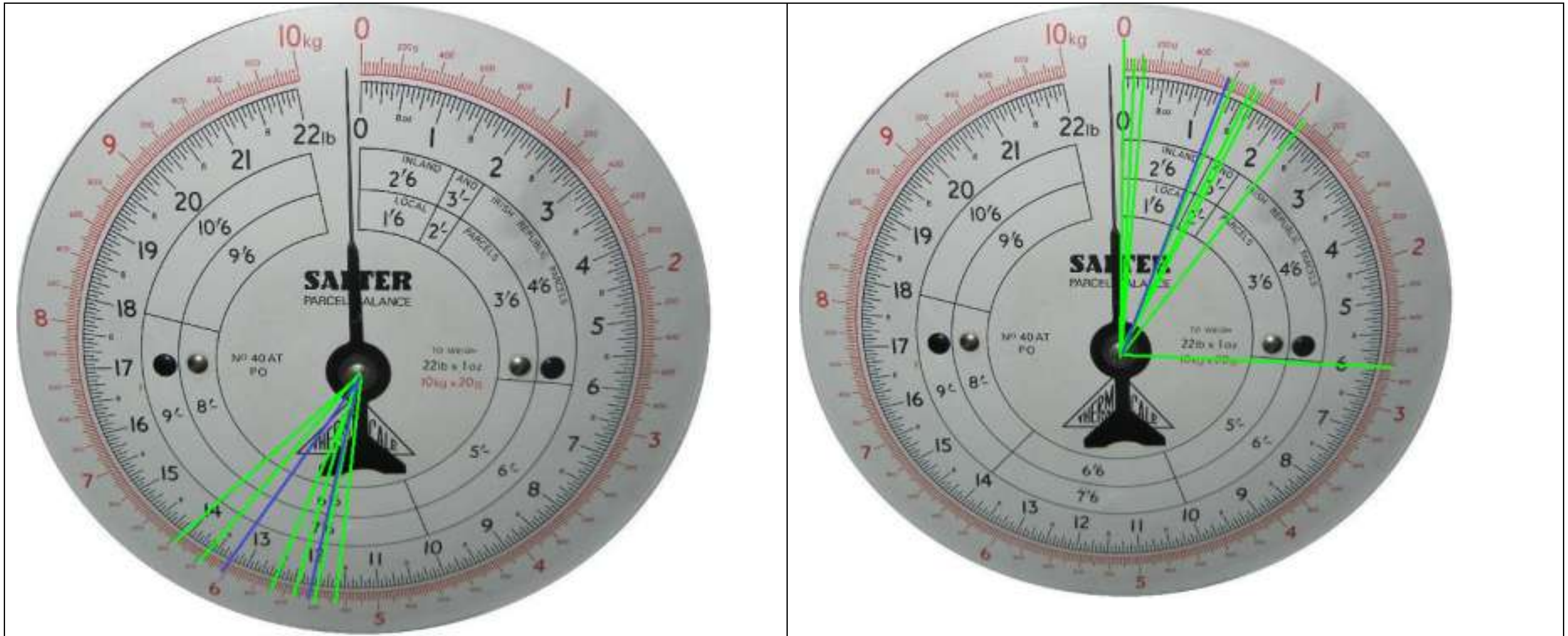


Figure 10.4: The distribution of blows recorded for test Subject 1 according to own judgement (left) and after training was provided (right). Each line in green represents a single blow, with blue lines representing 2 blows registering the same degree of downward force.

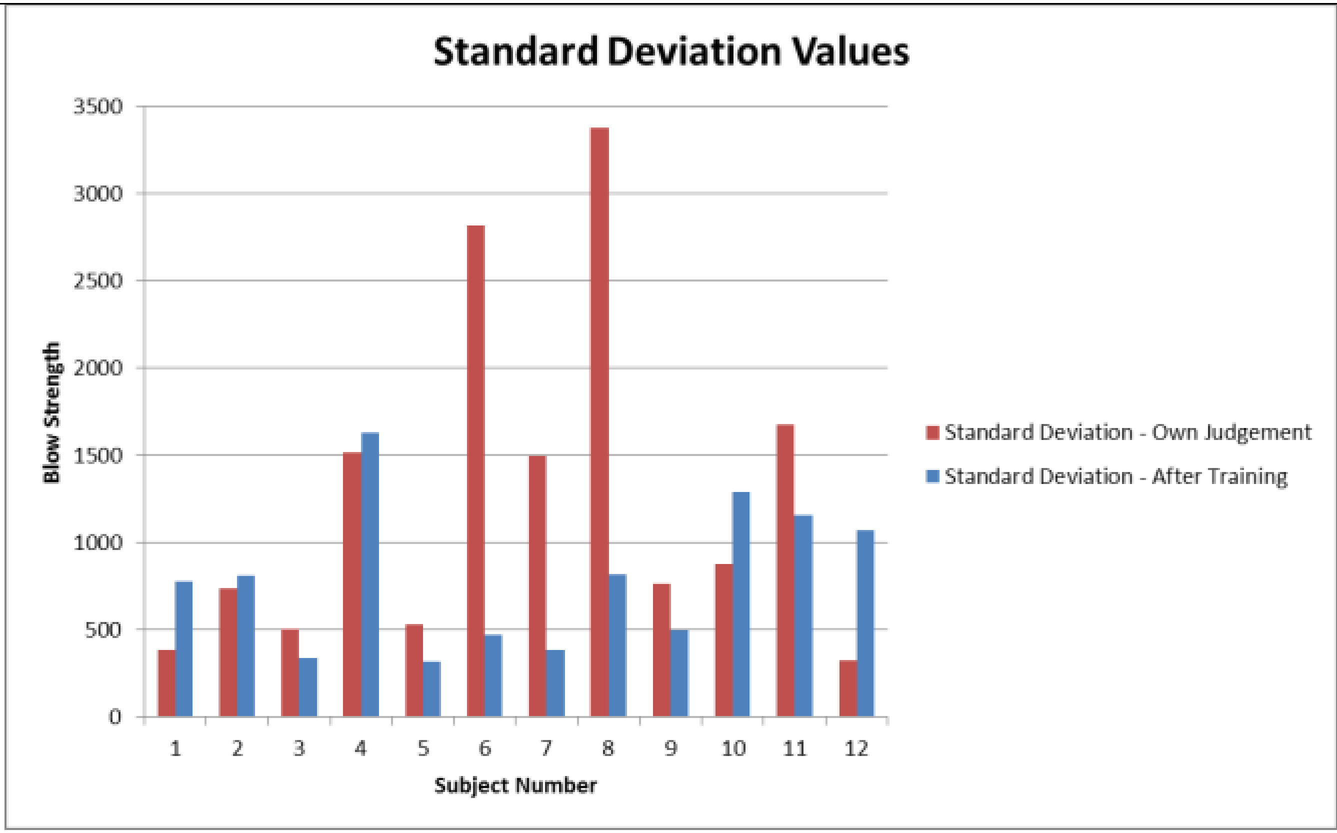


Figure 10.5: Comparison of standard deviations relating to blow strength scores for the 12 test participants when using their own judgement (red columns) and after training (blue columns).

10.2.3. Subject 2

Subject 2 overestimated the required blow strength as predicted when using her own judgement, and reduced the blow strengths applied after training. However, the blow strengths applied after training were not similar to those applied by James Dilley. Figure 10.6 charts the ten blows applied by Subject 2 in the two sets of conditions alongside those of James Dilley. One data point is missing for Subject 2 (Blow 10, using her own judgement).

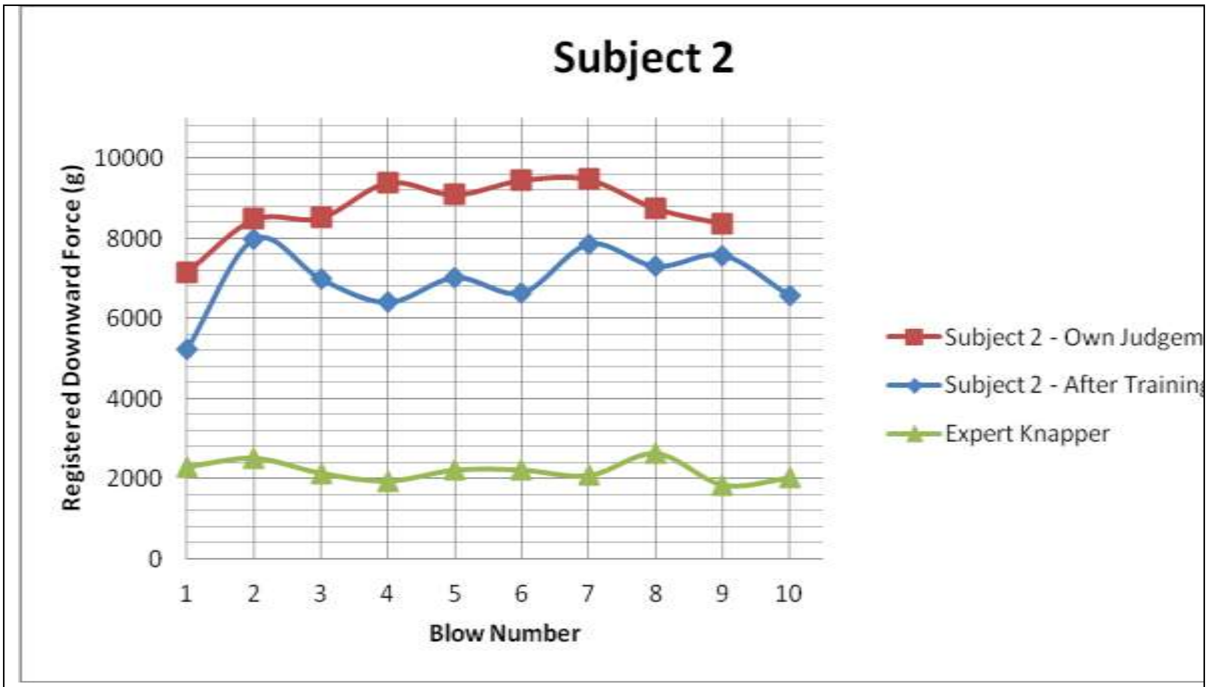


Figure 10.6: Line graph showing blows applied according to test Subject 2's own judgement (red), blows applied after a period of training (blue) and those applied by the expert knapper (green).

A. Measure of Central Tendency

Subject 2 showed a reasonable degree of consistency in both data sets as indicated by the mean and median scores. Using her own judgement she registered a mean blow strength of

8749 and a median of 8760, while after training he registered a mean blow strength of 6954 and a median of 7000 (see Figure 10.3). The data ranges, however, suggest a wide spread of blow strengths, with a range of 2320 for blows applied under her own judgement and a range of 2760 after training (all James Dilley's blows, in contrast, fell within a range of only 800).

Again, one can examine whether outliers may account for the high range scores, and the composite image indeed appears to show a single outlier in each of the two conditions may be skewing these figures (see Figure 10.7). If these data points are removed from the dataset, Subject 2 records a range of 1100 when using her own judgement and 1580 after training. Similar reductions in the ranges are not evident when eliminating any other single data point from either series, which suggests these two scores are indeed outliers.

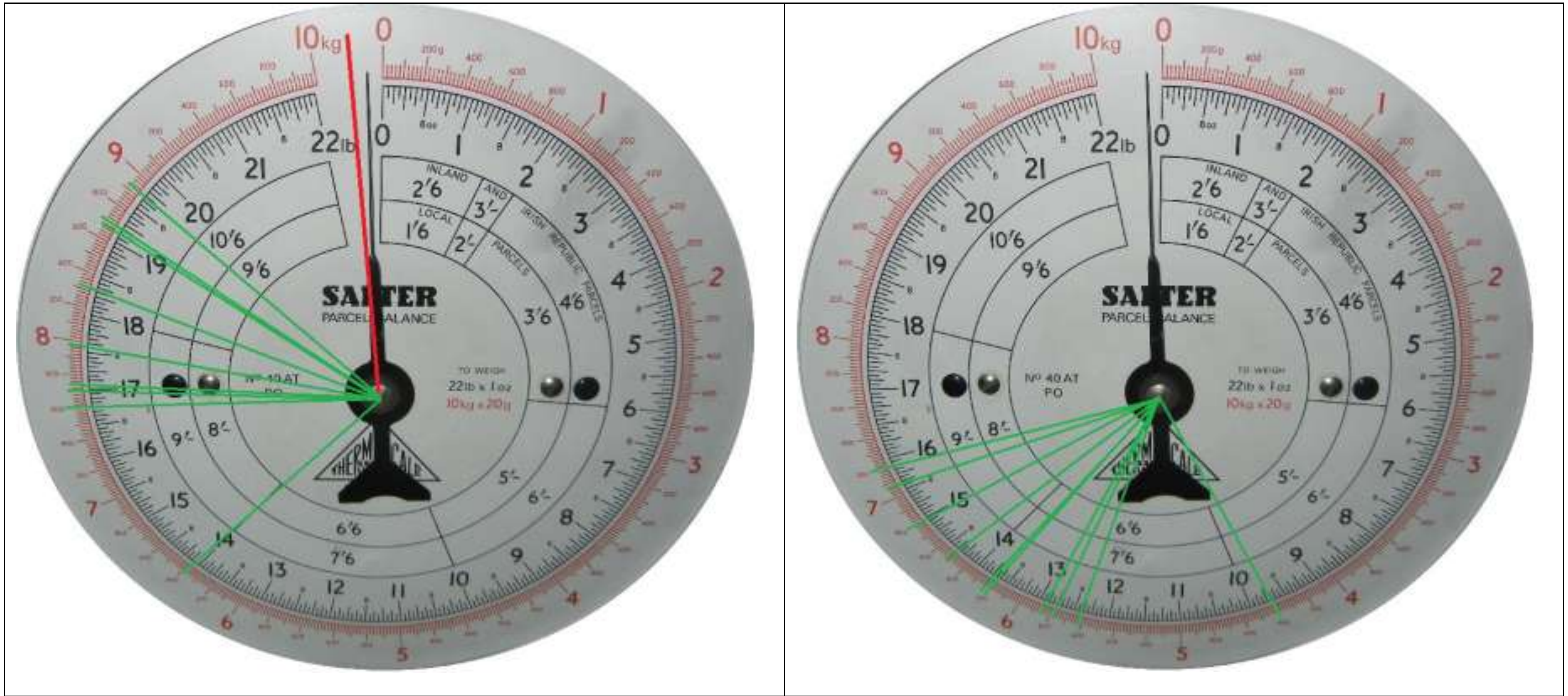


Figure 10.7: The distribution of blows recorded for test Subject 1 according to own judgement (left) and after training was provided (right). Each line in green represents a single blow and the red line indicating a missing data point.

B. Measure of Variance

In terms of variance, the data provided by Subject 2 exhibits a trend that was opposite to that hypothesised: i.e., less variance when using her own judgement (as indicated by a standard deviation of 739) and a higher degree of variance after a period of training as indicated by the standard deviation of 812 (see Figure 10.5). Given the outliers proposed above, both these figures may be skewed to an extent. Removing the outlier scores from the data set, however, produces a similar result: a standard deviation of 468 when using her own judgement, and a standard deviation of 572 after training. Again, therefore, Subject 2 displayed more consistency when using her own judgement even when the outliers are eliminated. An increase in consistency is therefore not evident for Subject 2 after the period of training.

10.2.4. Subject 3

Unusually, Subject 3 applied blows within the range used by James Dilley under both sets of conditions. Figure 10.8 charts the ten blows applied by Subject 3 in the two sets of conditions alongside those of James Dilley.

A. Measure of Central Tendency

Subject 3 showed a reasonable degree of consistency in both data sets as indicated the mean and median scores. Using his own judgement he registered a mean blow strength of 1660 and a median of 1560, while after training he registered a mean blow strength of 2138 and a median of 2090 (see Figure 10.3). The mean score registered after training was very close to the 2192 average recorded by the expert knapper. The range of the data recorded for Subject 3 after training suggests a high level of consistency, with a range of

960 (compared to 800 registered by James Dilley). In contrast, the data range recorded for Subject 3 when using his own judgement is comparatively higher, with a range of 1420. No notable outliers are identifiable from the composite image for the data in either of the two conditions examined (see Figure 10.9).

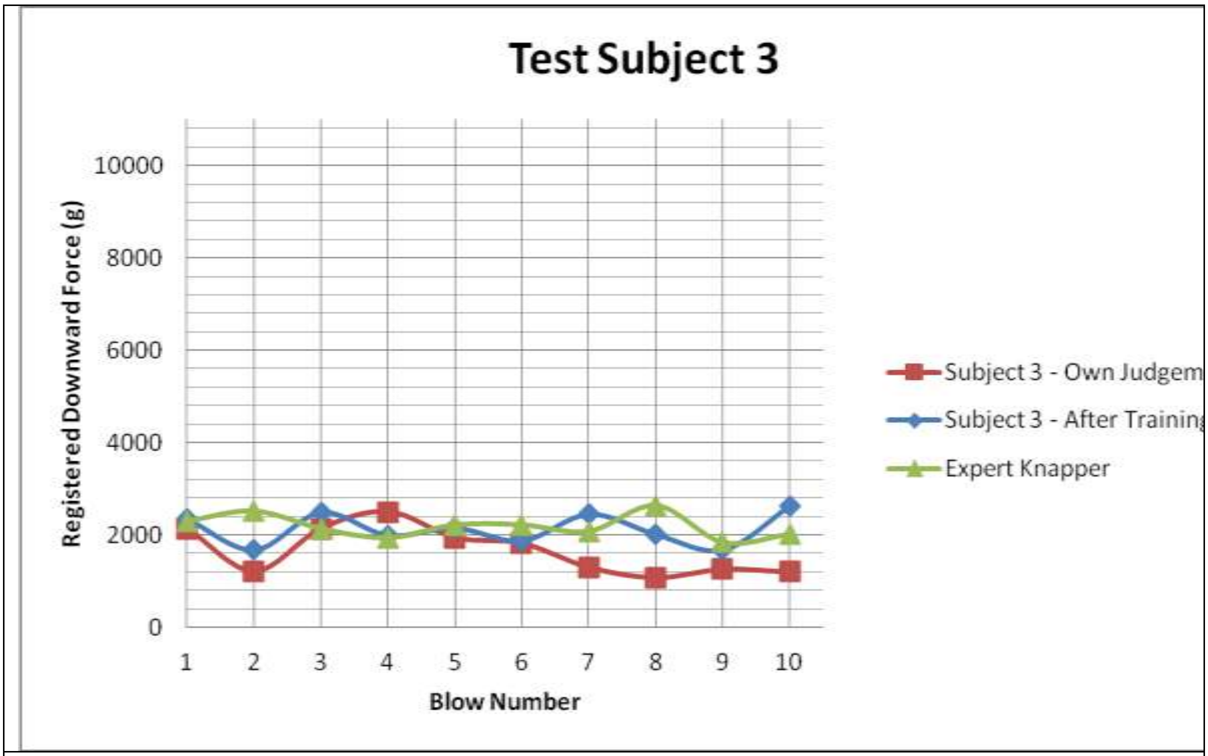


Figure 10.8: Line graph showing blows applied according to test Subject 3's own judgement (red), blows applied after a period of training (blue) and those applied by the expert knapper (green).

B. Measure of Variance

In terms of variance, the data provided by Subject 3 exhibits the trend hypothesised: i.e., less variance when applying blows within the ideal range. The standard deviation for the blow strengths recorded by Subject 3 when using his own judgement was 506, compared to a standard deviation of 343 for blows applied after training (see Figure 10.5). An increase in consistency is therefore evident for Subject 3 after the period of training.

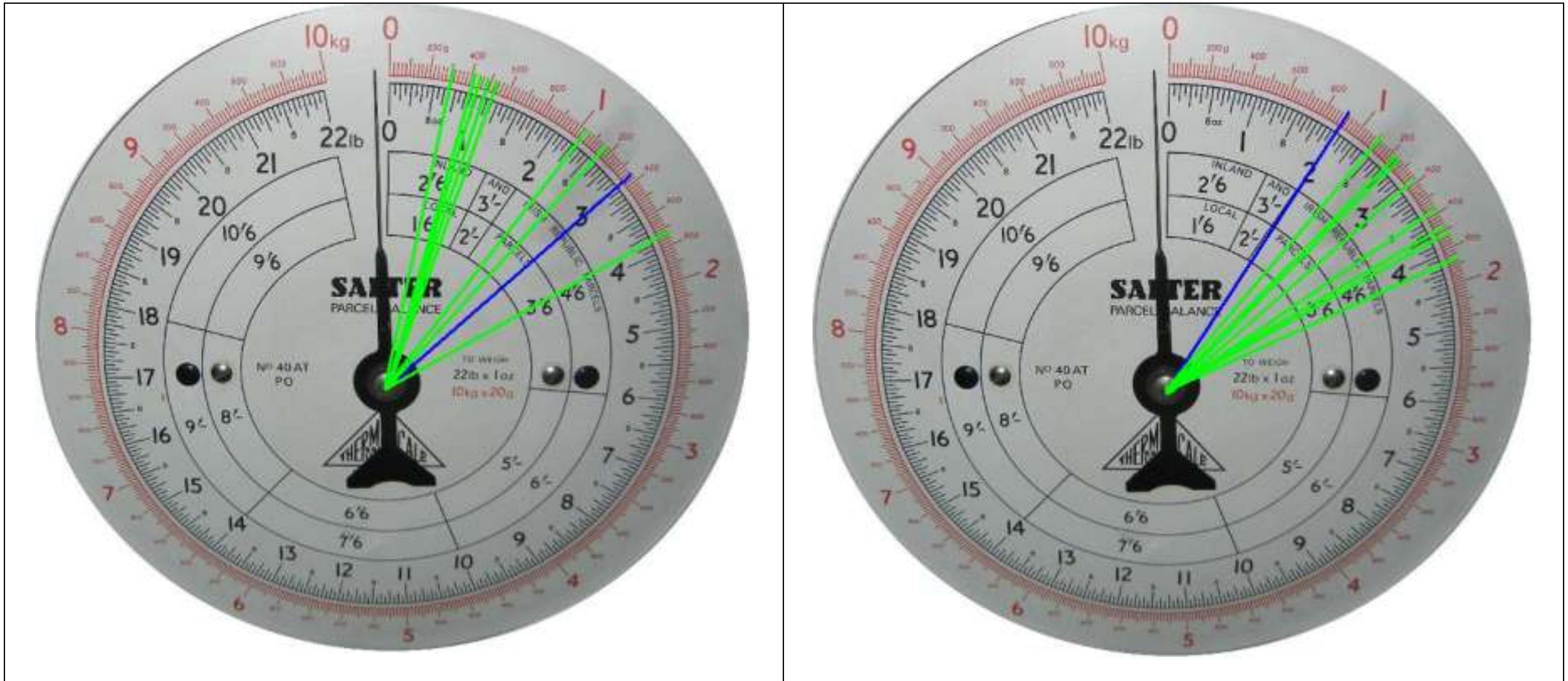


Figure 10.9: The distribution of blows recorded for test Subject 3 according to own judgement (left) and after training was provided (right). Each line in green represents a single blow, with blue lines representing 2 blows registering the same degree of downward force.

10.2.5. Subject 4

The average scores for Subject 4 suggest that she overestimated the required blow strength as predicted when using her own judgement, and reduced the blow strengths applied after training. However, as Figure 10.10 shows, Subject 4 was quite erratic when applying blows in both sets of conditions.

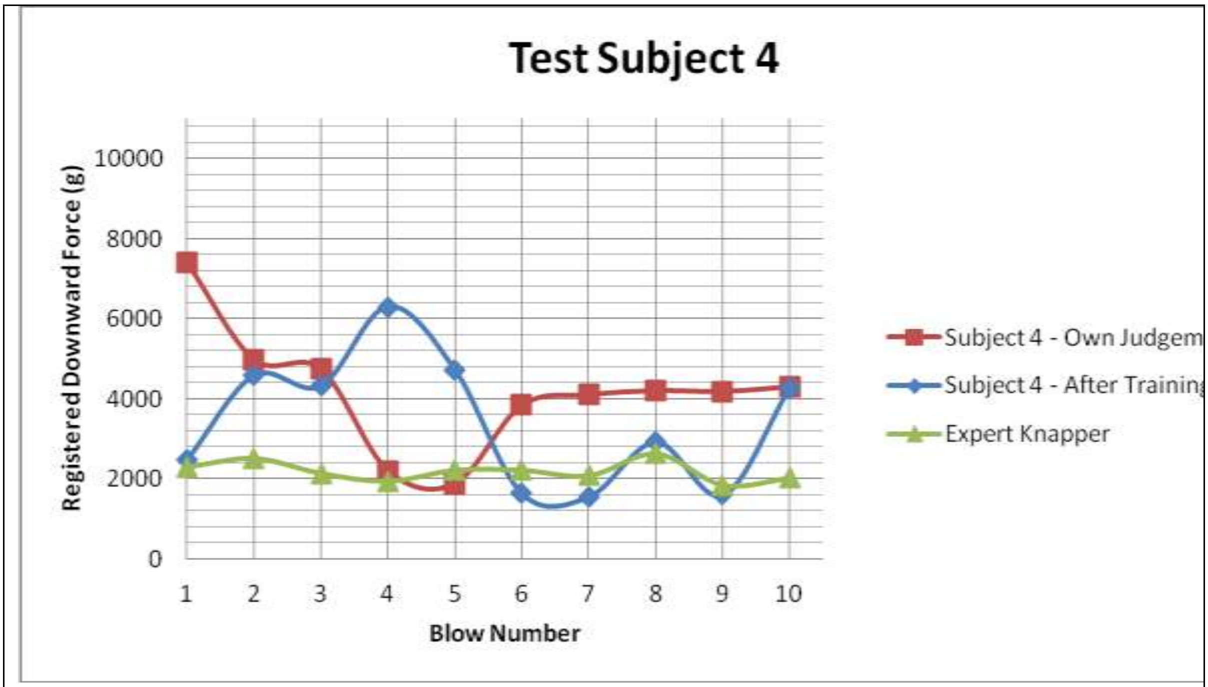


Figure 10.10: Line graph showing blows applied according to test Subject 4's own judgement (red), blows applied after a period of training (blue) and those applied by the expert knapper (green).

A. Measure of Central Tendency

The mean and median scores for Subject 4 appear to show a degree of consistency in both data sets. Using her own judgement she registered a mean blow strength of 4182 and a median of 4190, while after training she registered a mean blow strength of 3440 and a median of 3600 (see Figure 10.3).

The data ranges, however, suggest a wide spread of blow strengths, with a range of 5520 for blows applied under the test participant's own judgement and a range of 4740 after training. An examination of the composite images suggests some outliers may exist. For the blows applied under her own judgement, blows 1, 4 and 5 appear to be outliers from a main cluster (see Figure 10.11). In contrast, for the blows applied after training only blow 4 appears a distinct outlier, while the other blows fall within various other clusters. Removing these proposed outliers from the data sets improves the ranges slightly for the data set collected after training (range = 3160 when value for blow 4 is removed) and significantly for the data set collected when using her own judgement (range = 1140 when values for blows 1, 4 and 5 are removed).

B. Measure of Variance

In terms of variance, the data provided by Subject 4 exhibits a trend that was opposite to that hypothesised: i.e., less variance when using her own judgement when compared to blows applied after a period of training (as indicated by a standard deviation of 1516 for the former, and a standard deviation of 1631 for the latter) (see Figure 10.5). This trend is enhanced if one removes the outliers proposed above. Removing the data points for blows 1, 4 and 5 yields a standard deviation of 392 for blows applied using her own judgement. In contrast, removing blow 4 yields a standard deviation of 1363 for blows applied after training. On no interpretation of the data, therefore, is an increase in consistency evident for Subject 4 after the period of training.

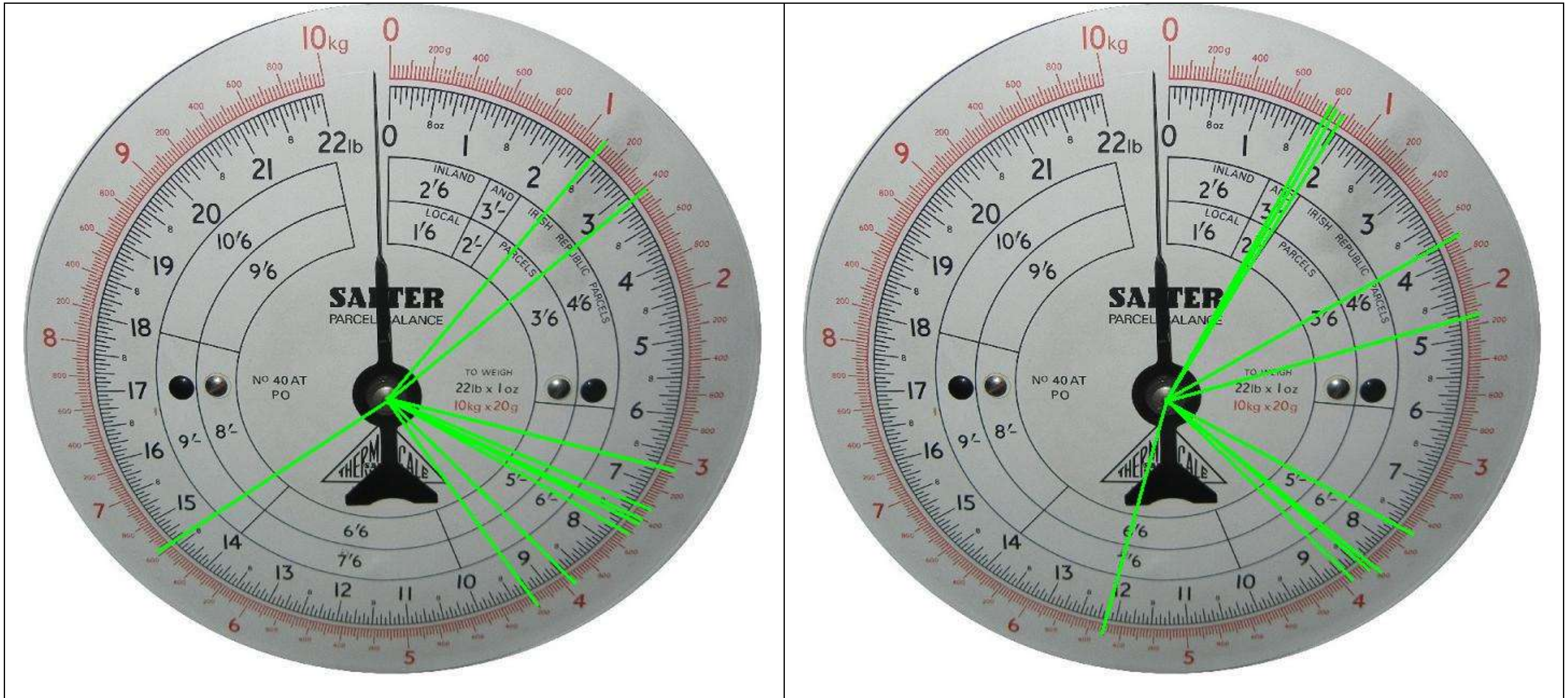


Figure 10.11: The distribution of blows recorded for test Subject 4 according to own judgement (left) and after training was provided (right). Each line in green represents a single blow.

10.2.6. Subject 5

Subject 5 overestimated the required blow strength when using his own judgement, and successfully adjusted the blow strengths applied after training. Figure 10.12 charts the ten blows applied by Subject 5 in the two sets of conditions alongside those of James Dilley.

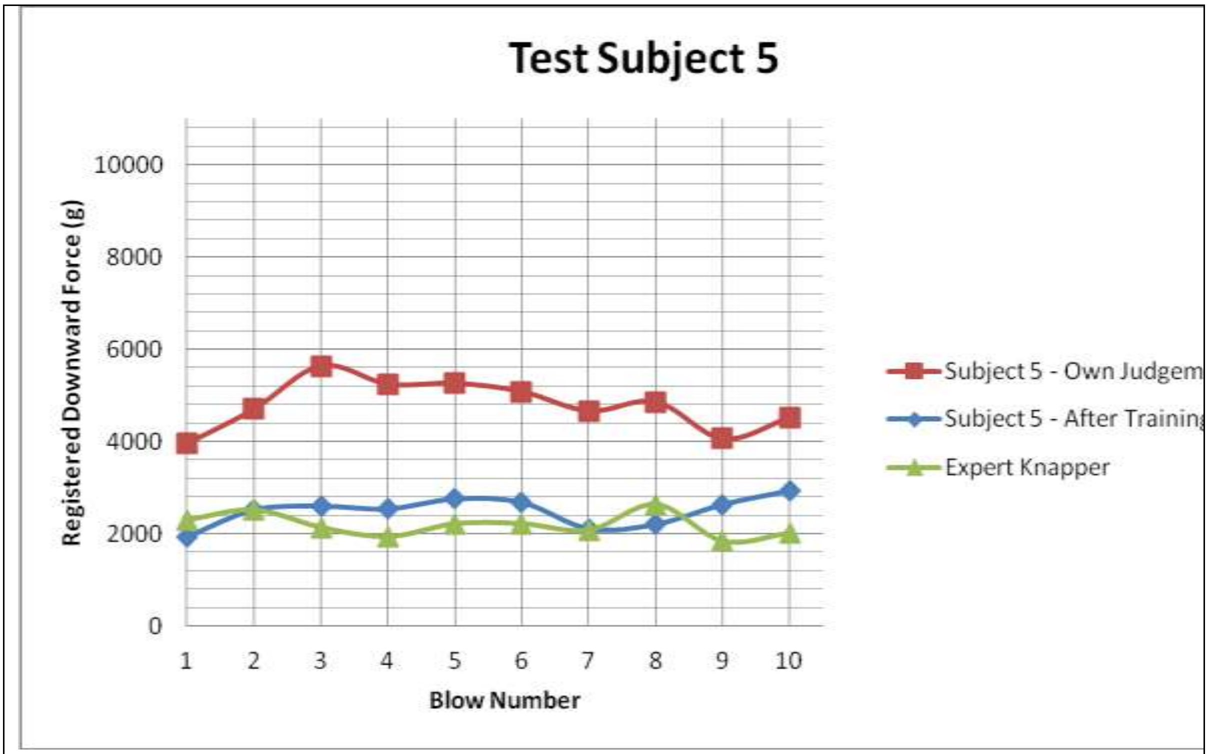


Figure 10.12: Line graph showing blows applied according to test Subject 5's own judgement (red), blows applied after a period of training (blue) and those applied by the expert knapper (green).

A. Measure of Central Tendency

Subject 5 showed a high level of consistency in both data sets. Using his own judgement he registered a mean blow strength of 4798 and a median of 4780, while after training he registered a mean blow strength of 2490 and a median of 2570 (see Figure 10.3).

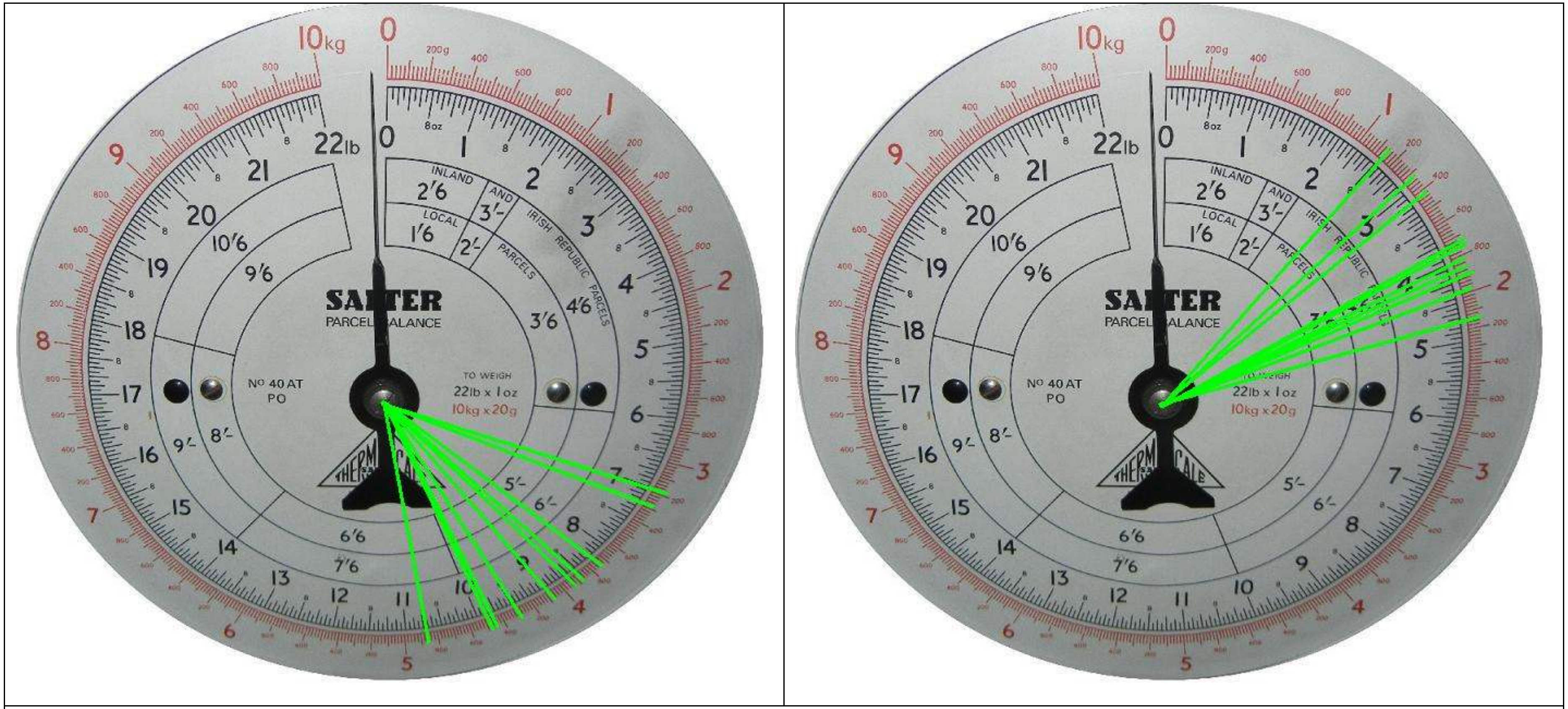


Figure 10.13: The distribution of blows recorded for test Subject 5 according to own judgement (left) and after training was provided (right). Each line in green represents a single blow.

The range of the data recorded for Subject 5 when using his own judgement suggests a decent level of consistency, with a range of 1680, while a range of 1020 was recorded after training, representing a distinct improvement. The composite image of registered blows displays clear blow clusters for all 10 blows under both conditions, with no obvious outliers (See Figure 10.13).

B. Measure of Variance

In terms of variance, the data provided by Subject 5 exhibits the trend originally hypothesised: i.e., more variance evident when the subject used their own judgement. The data provided by Subject 5 exhibited a standard deviation of 533 when using his own judgement and a standard deviation of 318 after training (this latter score is comparable to James Dilley's standard deviation of 248) (see Figure 10.5).

10.2.7. Subject 6

Subject 6 overestimated the required blow strength as predicted when using his own judgement, and reduced the blow strengths applied after training. However, as with Subject 2 the blow strengths applied after training were still stronger than those applied by James Dilley. Figure 10.14 charts the ten blows applied by Subject 6 in the two sets of conditions alongside those of James Dilley.

A. Measure of Central Tendency

Subject 6 displayed more consistency after training when compared with the use of his own judgement. When using his own judgement he registered a mean blow strength of 4798 and a median of 3350, while after training he registered a mean blow strength of

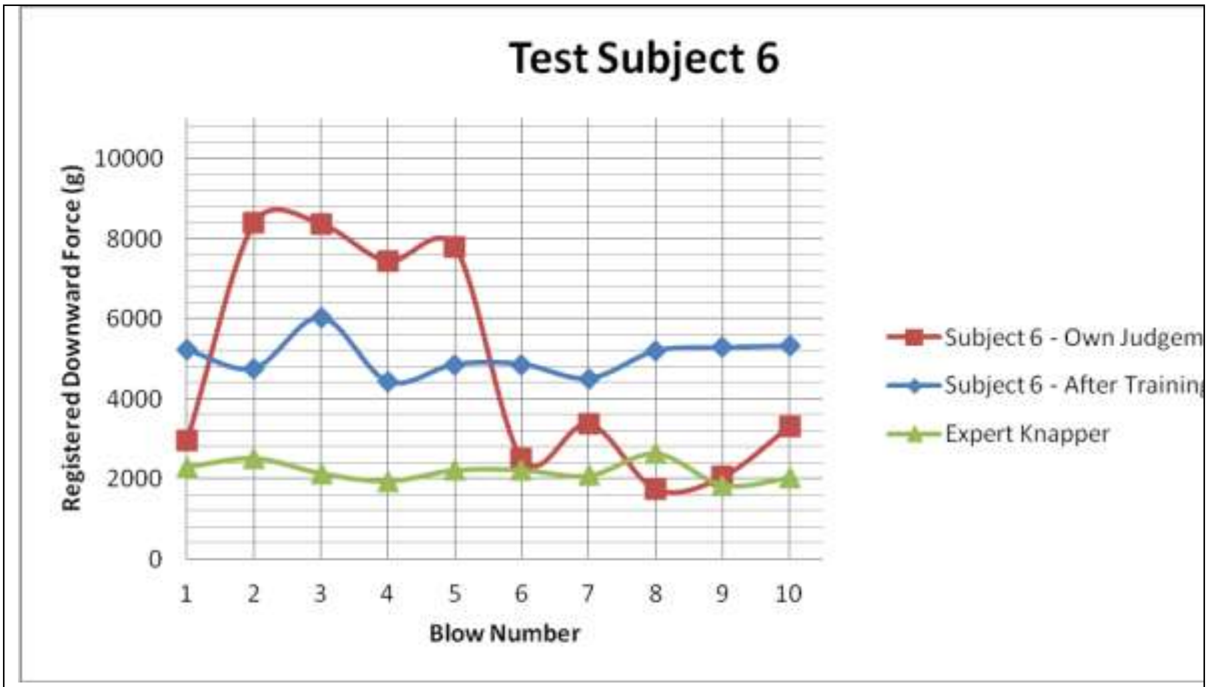


Figure 10.14: Line graph showing blows applied according to test Subject 6's own judgement (red), blows applied after a period of training (blue) and those applied by the expert knapper (green).

5046 and a median of 5030 (see Figure 10.3). The data ranges further support this interpretation, suggesting a wide spread of blow strengths for blows applied under the test participants own judgement (range = 6660) and a range of 1620 being recorded after training. An examination of the composite image indicates that outliers cannot account for the high range registered when the subject was using his own judgment. Figure 10.15 shows two distinct clusters of four blows which fall within a range between 7500g and 8500g of downward force, while the remainder register within a range more comparable to that recorded by James Dilley. Given that the former represent 40% of the blows applied, I would argue that they cannot be considered aberrations. The blows registered by Subject 6 after training, in contrast, present a tight cluster on the composite image (see Figure 10.15).

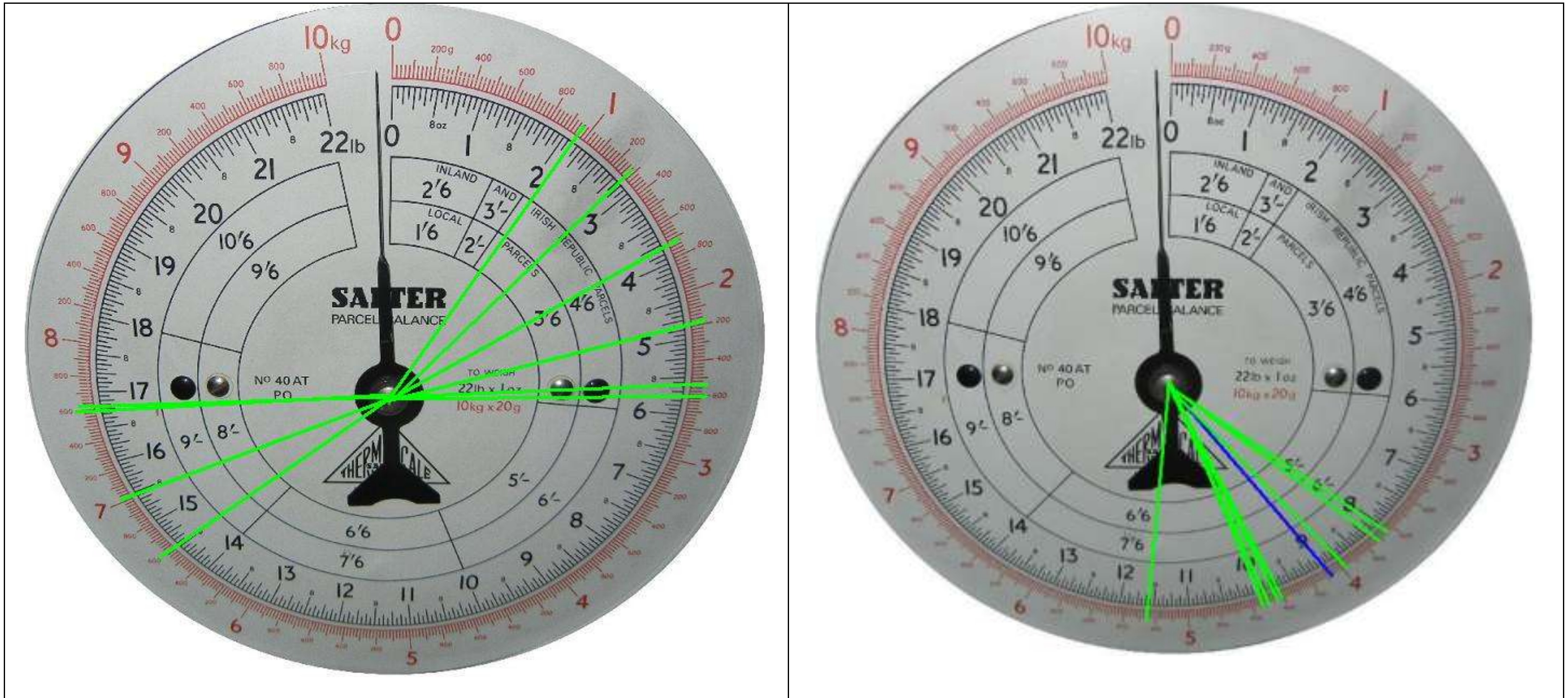


Figure 10.15: The distribution of blows recorded for test Subject 6 according to own judgement (left) and after training was provided (right). Each line in green represents a single blow, while the blue line represents 2 blows that registered the same degree of downward force.

B. Measure of Variance

In terms of variance, the data provided by Subject 6 exhibits a trend consistent with that hypothesised: i.e., more variance when using his own judgement (as indicated by a standard deviation of 2819) and less variance after a period of training as indicated by the standard deviation of 473 (see Figure 10.5). A significant increase in consistency is therefore evident for Subject 6 after the period of training. Indeed, if the 4 heavy blows noted above are eliminated, the 'own judgment' data set still displays more variance than the 'after training' data set (standard deviation = 675 based on the 6 remaining blows). Finally, it is worth noting that this subject did the training first, and so was initially consistent when guided, but then inconsistent when asked to use his own judgement.

10.2.8. Subject 7

Subject 7 overestimated the required blow strength when using his own judgement, and successfully adjusted the blow strengths applied after training. However, the blow strengths applied after training were still more forceful than those applied by James Dilley. Figure 10.16 charts the ten blows applied by Subject 7 in the two sets of conditions alongside those of James Dilley. One data point is missing for Subject 7 (Blow 4, using his own Judgement).

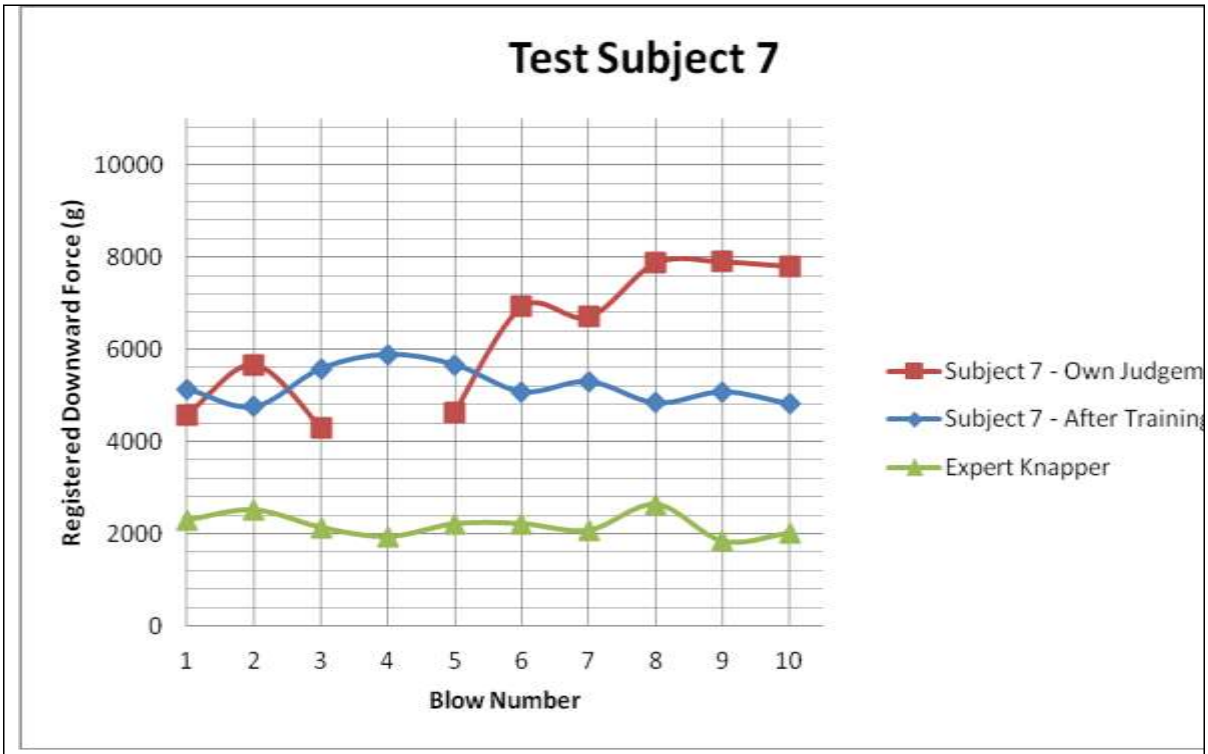


Figure 10.16: Line graph showing blows applied according to test Subject 7's own judgement (red), blows applied after a period of training (blue) and those applied by the expert knapper (green).

A. Measure of Central Tendency

Subject 7 showed more consistency after training than when using his own judgement. When using his own judgement he registered a mean blow strength of 6262 and a median of 6700, while after training he registered a mean blow strength of 5214 and a median of 5110 (see Figure 10.3). The range of the data recorded for Subject 7 similarly suggests that when using his own judgement Subject 7 was less consistent, with a range of 3620 compared to a range of 1120 after training. In addition, the composite image clearly shows the wider distribution of blow strengths when Subject 7 was using his own judgement, and a tighter cluster for the blows applied after training, with no obvious outliers (See Figure 10.17).

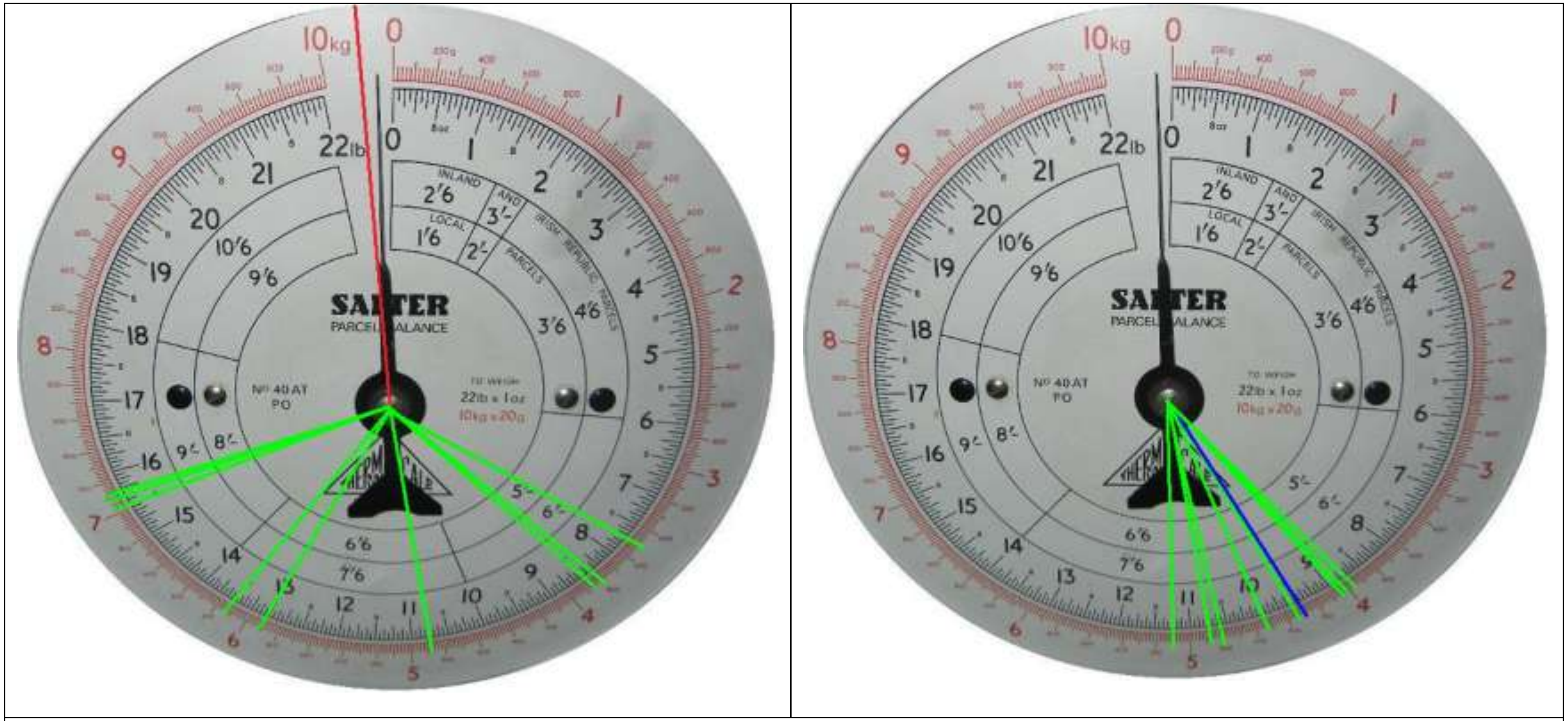


Figure 10.17: The distribution of blows recorded for test Subject 7 according to own judgement (left) and after training was provided (right). Each line in green represents a single blow, the blue line represents 2 blows that registered the same degree of downward force, and the red line indicating a missing data point.

B. Measure of Variance

In terms of variance, the data provided by Subject 7 exhibits the trend hypothesised: i.e., more variance was evident when the subject used their own judgement. The data provided by Subject 7 exhibited a standard deviation of 1502 when using his own judgement and a standard deviation of 384 after training (this latter score is comparable to James Dilley's standard deviation of 248) (see Figure 10.5). Of the two conditions under which Subject 7 was tested, therefore, he displayed more consistency after the period of training.

10.2.9. Subject 8

Subject 8 overestimated the required blow strength as predicted when using her own judgement, and reduced the blow strengths applied after training. However, the blow strengths applied after training were not similar to those applied by James Dilley. Figure 10.18 charts the ten blows applied by Subject 8 in the two sets of conditions alongside those of James Dilley.

A. Measure of Central Tendency

Subject 8 showed more consistency after training than when using his own judgement. Using her own judgement she registered a mean blow strength of 7786 and a median of 9690, while after training he registered a mean blow strength of 5724 and a median of 5570 (see Figure 10.3). The data ranges further support this interpretation, with a range of 8260 for blows applied under the test participants own judgement and a range of 2400 after training.

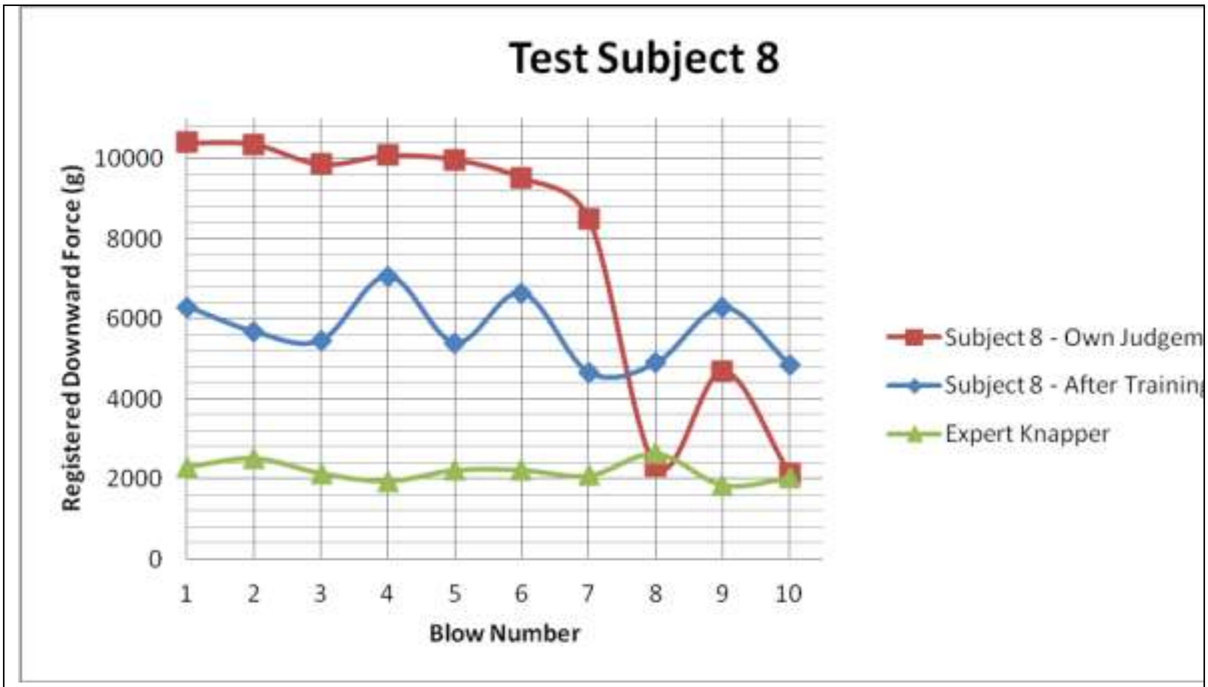


Figure 10.18: Line graph showing blows applied according to test Subject 8's own judgement (red), blows applied after a period of training (blue) and those applied by the expert knapper (green).

Again, one can examine the composite image to assess whether outliers exist, and one could argue that the three lowest scores recorded when Subject 8 was using her own judgement could be outliers (i.e., blows 8, 9 and 10) (see Figure 10.19). Excluding these scores reduces the range from 8260 to 1900 and brings the mean and median scores closer together (mean =9814, median = 9980). No equivalent outliers are evident in the blows applied after training, with all 10 blows being distributed evenly within the cluster.

B. Measure of Variance

In terms of variance, the data provided by Subject 8 concurs with the trend originally hypothesised: i.e., more variance was evident when the subject used their own judgement. The data provided by Subject 8 exhibited a standard deviation of 3377 when using her own judgement and a standard deviation of 816 after training (see Figure 10.5).

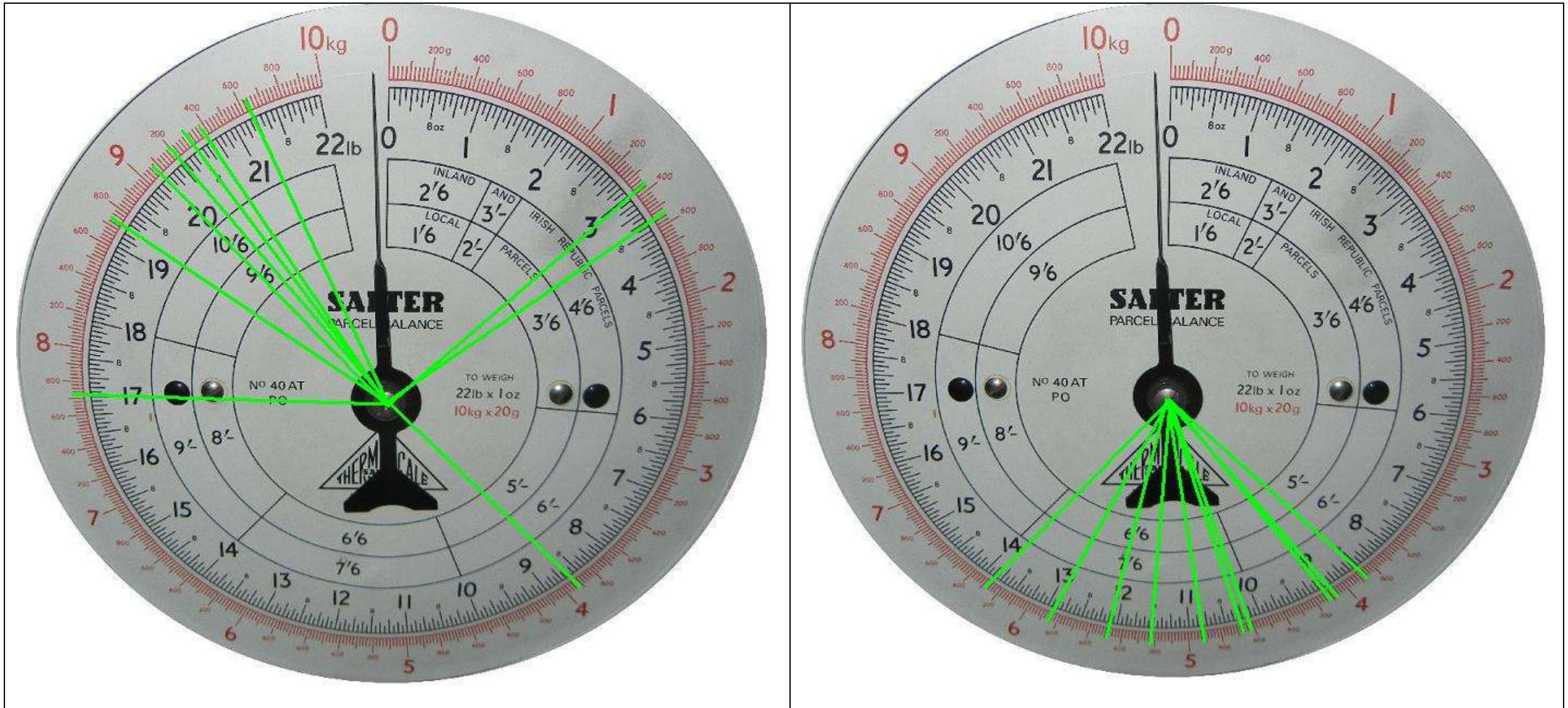


Figure 10.19: The distribution of blows recorded for test Subject 8 according to own judgement (left) and after training was provided (right). Each line in green represents a single blow.

Prima facie, therefore, Subject 8 displayed more consistency after the period of training. The reverse is true, however, if one eliminates the proposed outliers identified above.

10.2.10. Subject 9

Rather surprisingly, Subject 9 applied blows within the range used by James Dilley when using her own judgement and overestimated the blows strengths required after training. Figure 10.20 charts the ten blows applied by Subject 9 in the two sets of conditions alongside those of James Dilley.

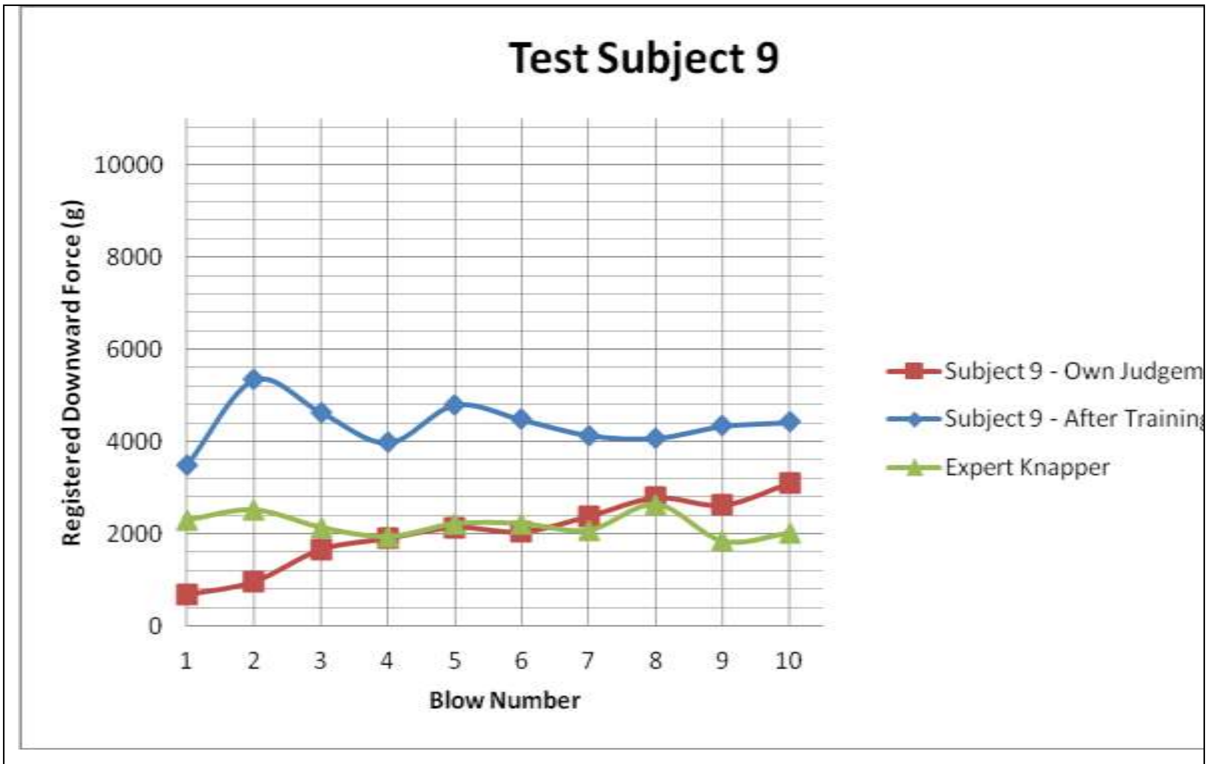


Figure 10.20: Line graph showing blows applied according to test Subject 9's own judgement (red), blows applied after a period of training (blue) and those applied by the expert knapper (green).

A. Measure of Central Tendency

Subject 9 showed a reasonable degree of consistency in both data sets as indicated by the mean and median scores. Using her own judgement she registered a mean blow strength of 2026 and a median of 2090, while after training she registered a mean blow strength of 4372 and a median of 4380 (see Figure 10.3). The mean score registered when using her own judgement were very close to the 2192 average recorded by the expert knapper.

The range of data recorded for Subject 9 in both conditions display a degree of consistency, with a range of 2420 registered when using her own judgement and a range of 1840 after training. No notable outliers are identifiable from the composite image for the data in either of the two conditions examined (see Figure 10.21).

B. Measure of Variance

In terms of variance, the data provided by Subject 9 exhibits the trend hypothesised: i.e., less variance when attempting to apply blows within the ideal range. The standard deviation for the blow strengths recorded by Subject 9 when using her own judgement was 768, compared to a standard deviation of 501 for blows applied after training (see Figure 10.5). An increase in consistency is therefore evident for Subject 9 after the period of training.

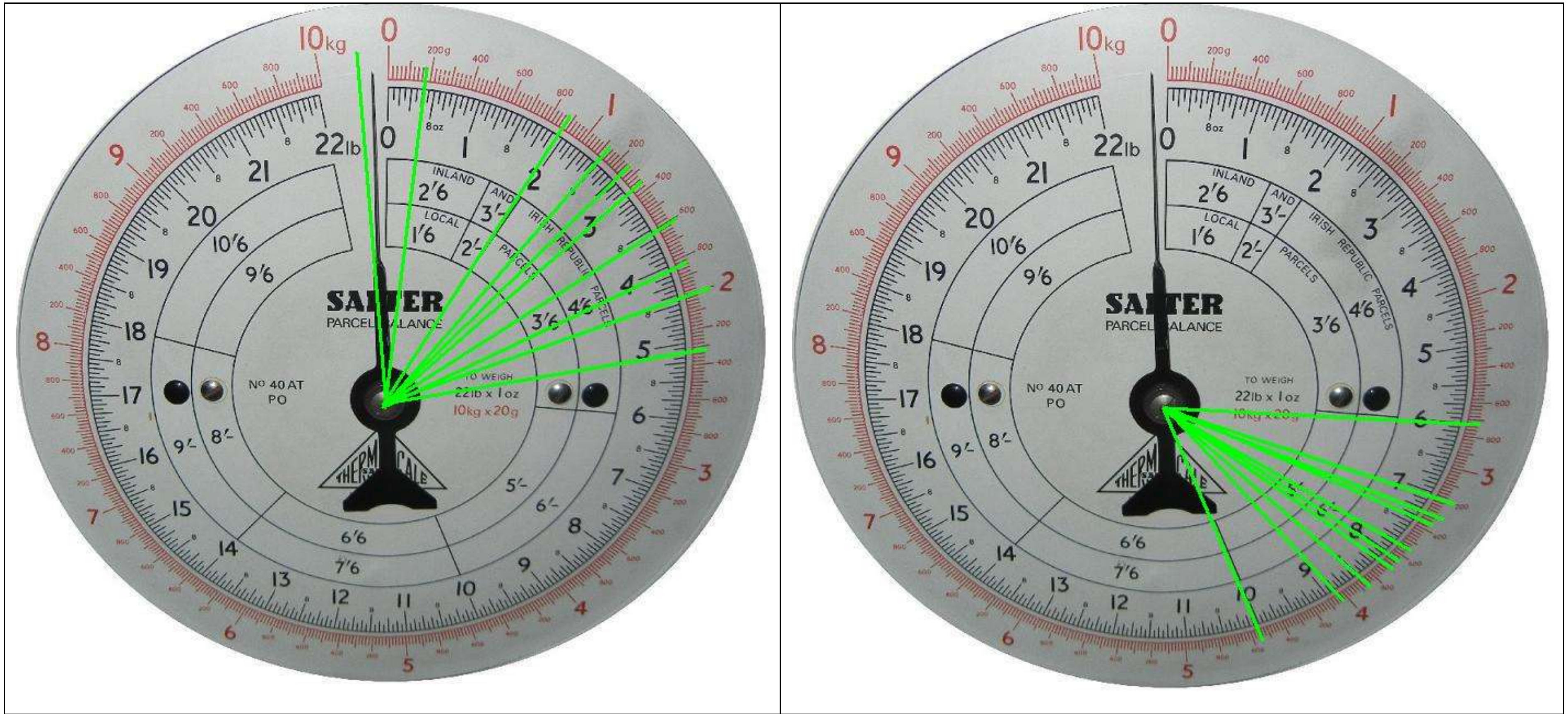


Figure 10.21: The distribution of blows recorded for test Subject 9 according to own judgement (left) and after training was provided (right). Each line in green represents a single blow.

10.2.11. Subject 10

Subject 10 overestimated the required blow strength as predicted when using his own judgement, and reduced the blow strengths applied after training. However, the blow strengths applied after training were not similar to those applied by James Dilley. Figure 10.22 charts the ten blows applied by Subject 10 in the two sets of conditions alongside those of James Dilley.

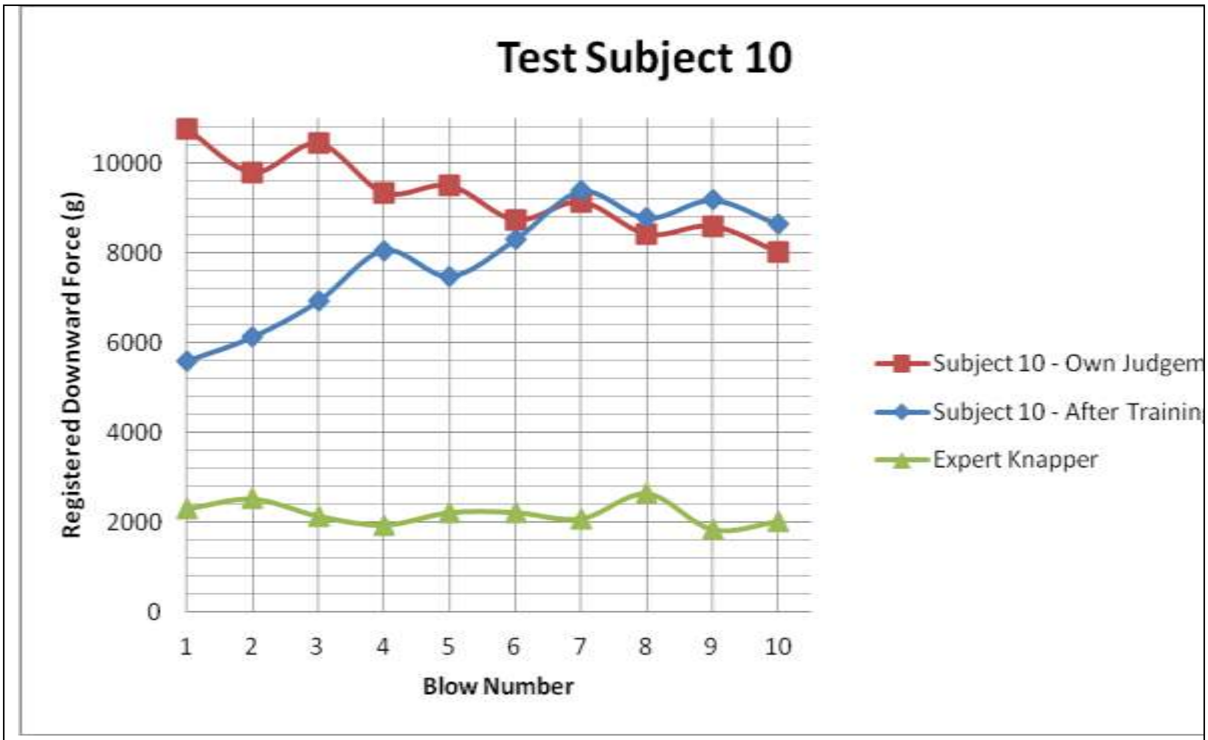


Figure 10.22: Line graph showing blows applied according to test Subject 10's own judgement (red), blows applied after a period of training (blue) and those applied by the expert knapper (green).

A. Measure of Central Tendency

Subject 10 showed a reasonable degree of consistency in both data sets as indicated the mean and median scores. Using his own judgement he registered a mean blow strength of 9276 and a median of 9240, while after training he registered a mean blow strength of

7844 and a median of 8180 (see Figure 10.3). The data ranges, however, suggest a wide spread of blow strengths, with a range of 2740 for blows applied under the test participants own judgement and a range of 3800 after training. An examination of the composite images indicates there are no clear outliers, with both data sets presenting clusters that are widely, but also evenly, distributed (see Figure 10.23).

B. Measure of Variance

In terms of variance, the data provided by Subject 10 exhibits a trend that was the opposite to that hypothesised: i.e., less variance when using his own judgement (as indicated by a standard deviation of 879) and a higher degree of variance after a period of training as indicated by the standard deviation of 1291 (see Figure 10.5). An increase in consistency is therefore not evident for Subject 10 after the period of training, though arguably the results are difficult to interpret for Subject 10 due to a failure to adjust the applied blow strengths in response to the training.

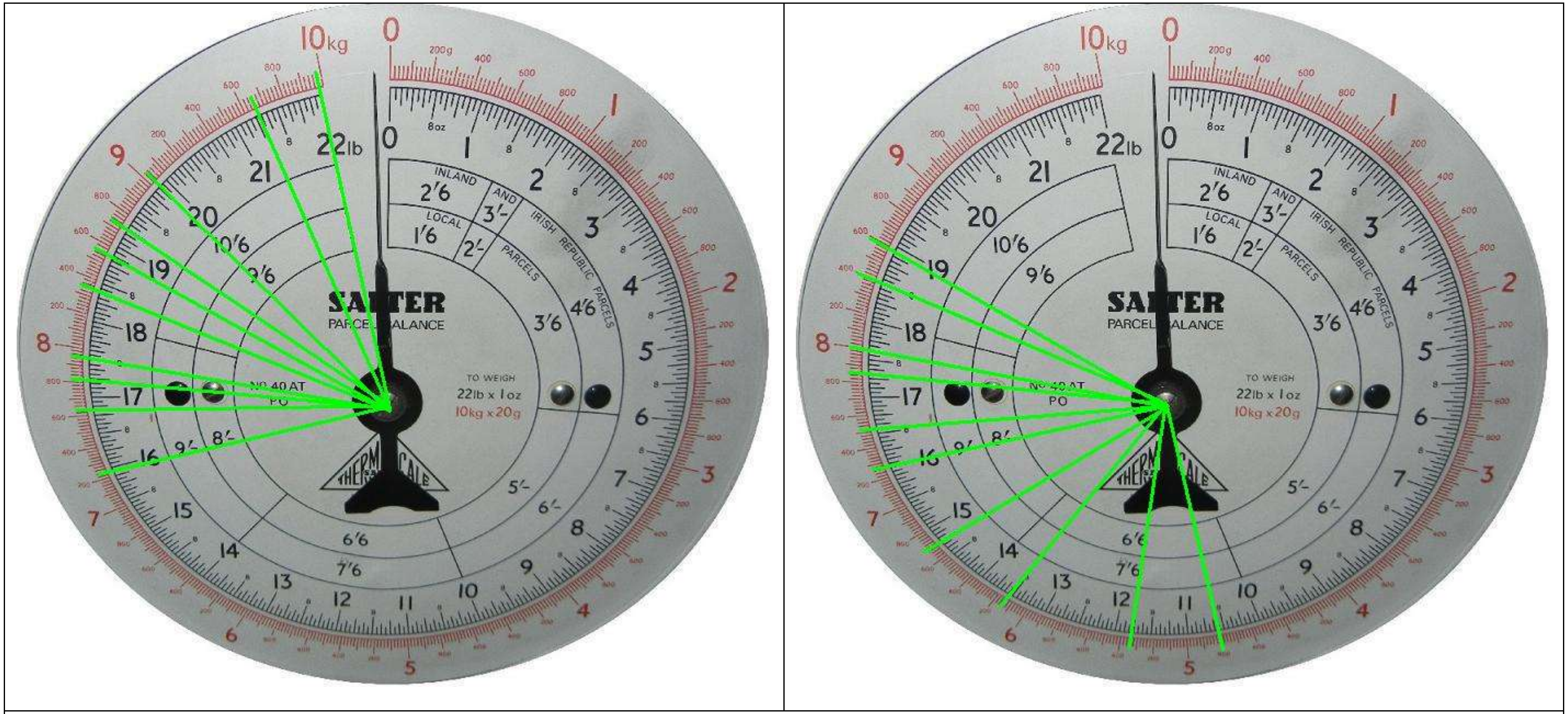


Figure 10.23: The distribution of blows recorded for test Subject 10 according to own judgement (left) and after training was provided (right). Each line in green represents a single blow.

10.2.12. Subject 11

When using his own judgement Subject 11 overestimated the required blow strength, and successfully adjusted the blow strengths applied after training to within the desired range. Figure 10.24 charts the ten blows applied by Subject 11 in the two sets of conditions alongside those of James Dilley.

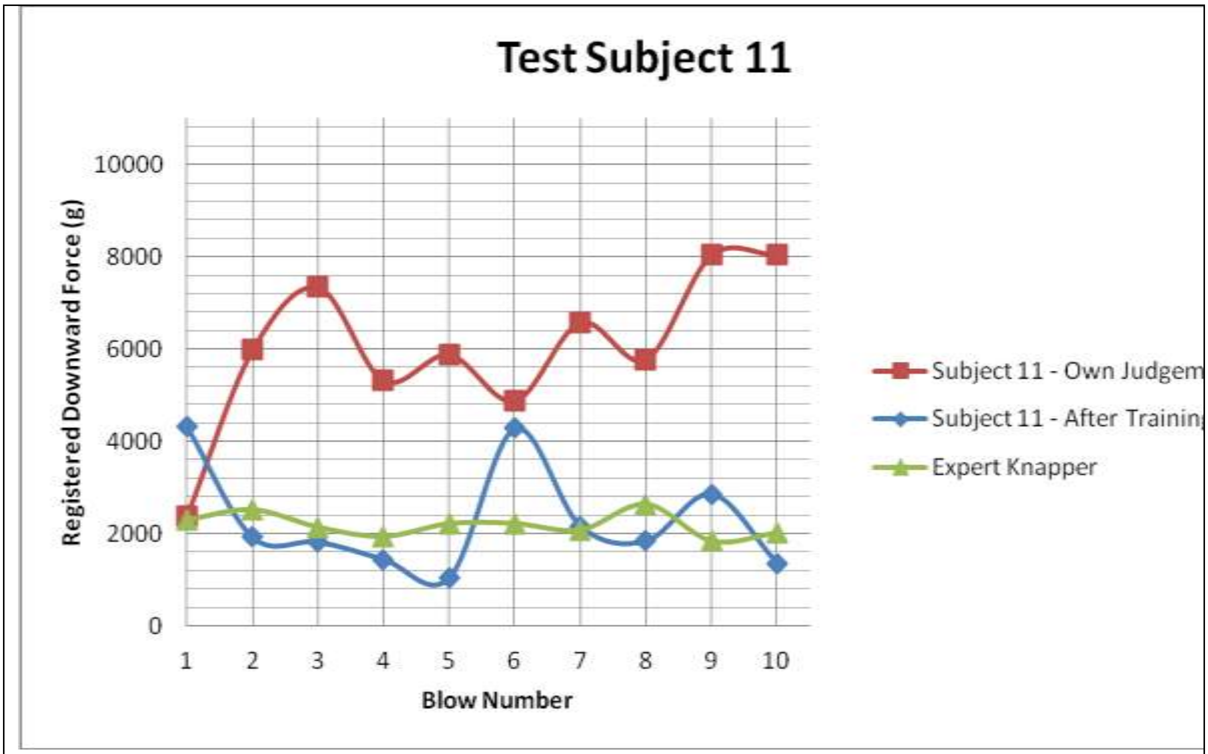


Figure 10.24: Line graph showing blows applied according to test Subject 11's own judgement (red), blows applied after a period of training (blue) and those applied by the expert knapper (green).

A. Measure of Central Tendency

Subject 11 showed a degree of consistency in both data sets. Using his own judgement he registered a mean blow strength of 6022 and a median of 5930, while after training he registered a mean blow strength of 2304 and a median of 1880 (see Figure 10.3). The range of the data recorded for Subject 11 suggests a wider spread of blows when using his own judgement (range = 5660) compared to the blows applied after training (range = 3280). From examining the composite images (Figure 10.25) one could argue that outliers exist for both data sets: for the data collected when Subject 11 used his own judgement blow 1 appears to be outlier, while for the data collected after training blows 1 and 6 similarly appear to be outliers.

B. Measure of Variance

In terms of variance, the data provided by Subject 11 concurs with the trend originally hypothesised: i.e., more variance was evident when the subject used his own judgement. The data provided by Subject 11 exhibited a standard deviation of 1678 when using his own judgement and a standard deviation of 1161 after training (see Figure 10.5). If the outliers noted above are removed from the data a similar trend is evident, with a standard deviation of 1151 for data collected when Subject 11 used his own judgement (minus blow 1) and a standard deviation of 557 for data collected after training (minus blows 1 and 6). An increase in consistency is therefore evident for Subject 11 after the period of training when compared to the use of his own judgement whether or not adjustments are made to account for the outliers.

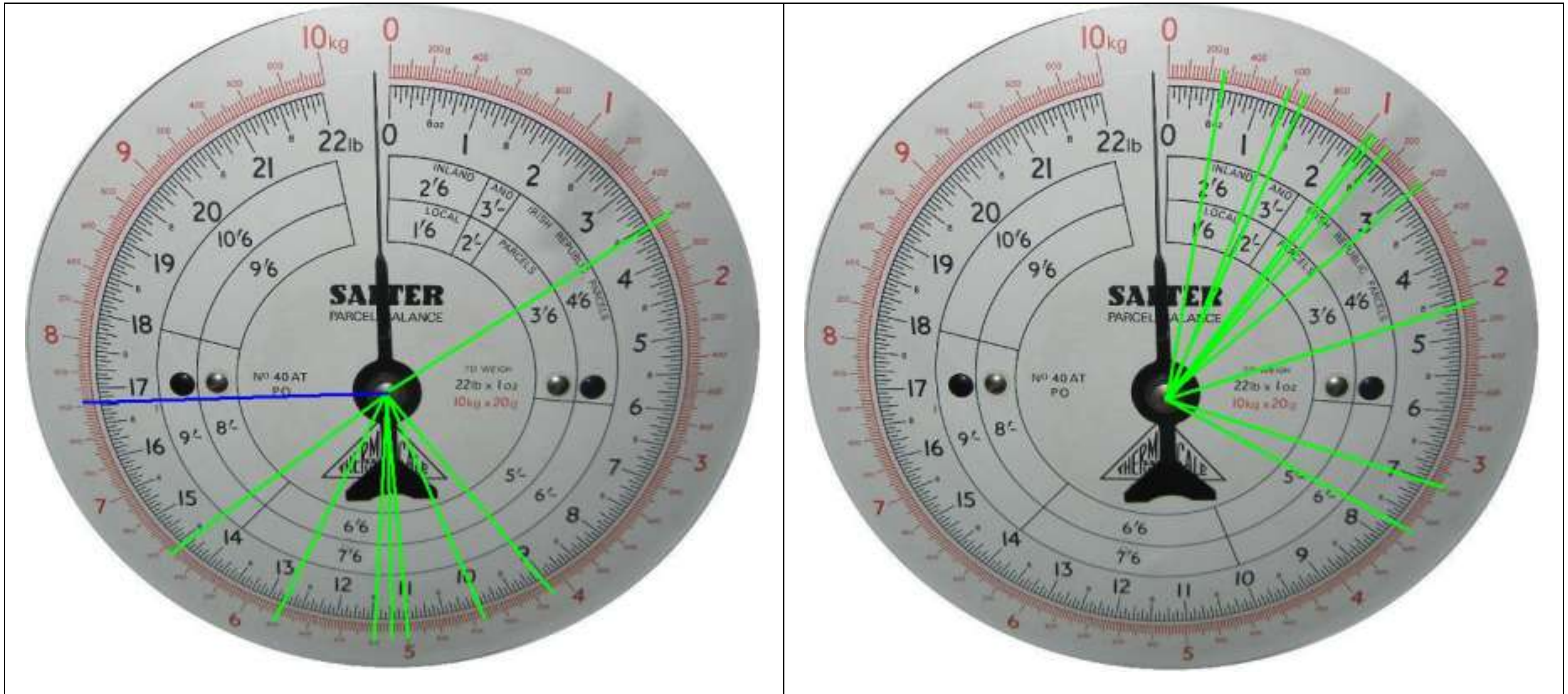


Figure 10.25: The distribution of blows recorded for test Subject 11 according to own judgement (left) and after training was provided (right). Each line in green represents a single blow, while the blue line represents 2 blows that registered the same degree of downward force.

10.2.13. Subject 12

When using his own judgement Subject 12 overestimated the required blow strength, and successfully adjusted the blow strengths applied after training to within the desired range. Figure 10.26 charts the ten blows applied by Subject 12 in the two sets of conditions alongside those of James Dilley.

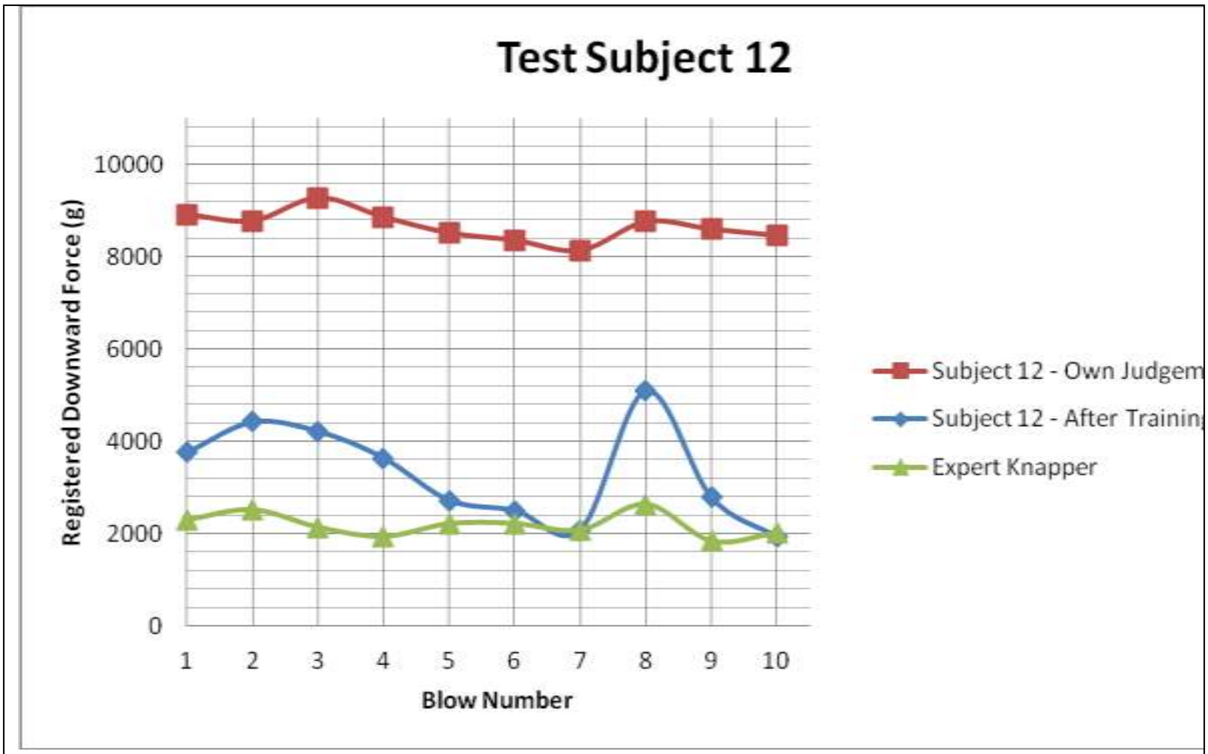


Figure 10.26: Line graph showing blows applied according to test Subject 12's own judgement (red), blows applied after a period of training (blue) and those applied by the expert knapper (green).

A. Measure of Central Tendency

Subject 12 showed a degree of consistency in both data sets. Using his own judgement he registered a mean blow strength of 8668 and a median of 8680, while after training he registered a mean blow strength of 3314 and a median of 3210 (see Figure 10.3).

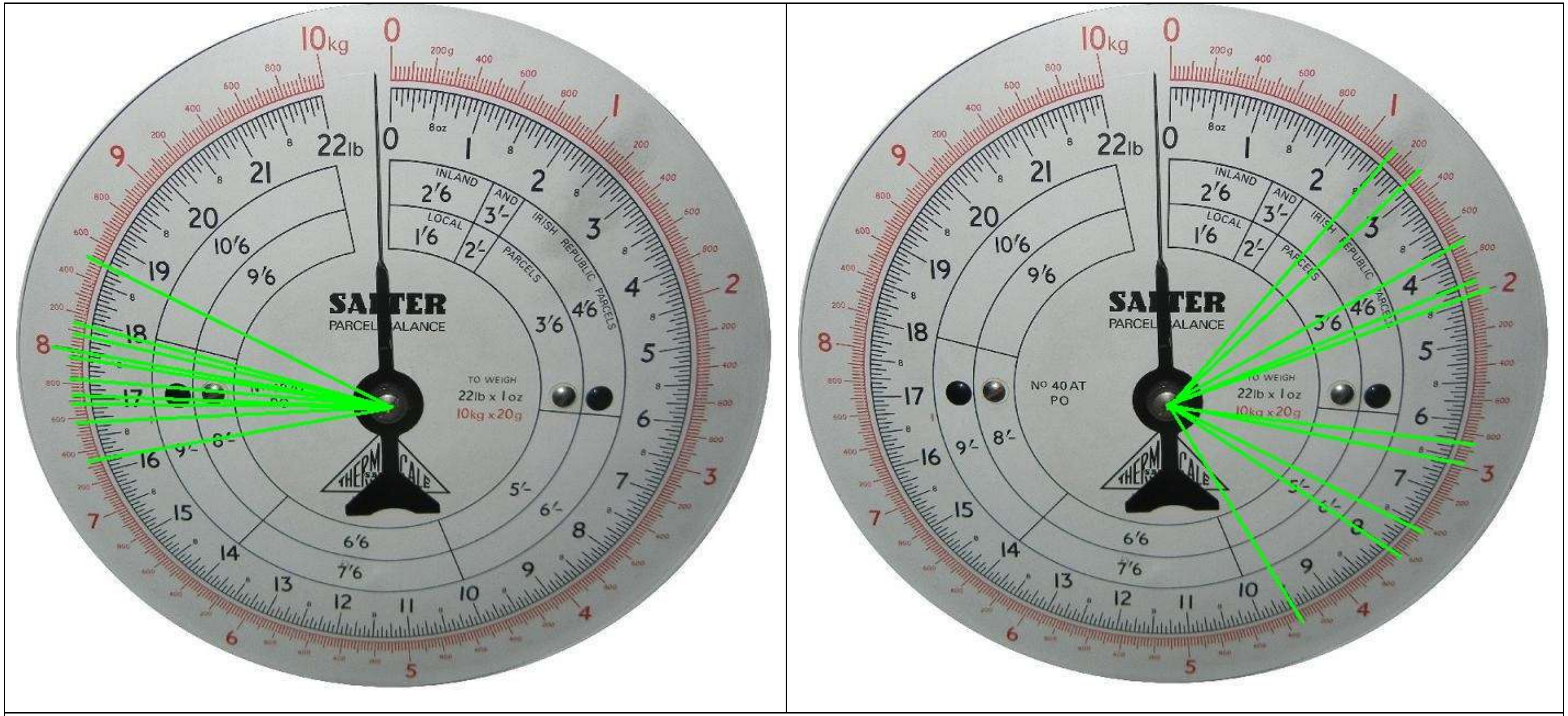


Figure 10.27: The distribution of blows recorded for test Subject 12 according to own judgement (left) and after training was provided (right). Each line in green represents a single blow.

The range of the data recorded for Subject 12 suggests a wider spread of blows after training (range = 3180) than when using his own judgement (range = 1140). The composite images supports this interpretation, with a wide spread of blows evident after training compared to the tight cluster achieved by Subject 12 when using his own judgment (see Figure 10.27). No outliers are evident for either data set.

B. Measure of Variance

In terms of variance, the data provided by Subject 12 exhibits a trend that was opposite to that hypothesised: i.e., less variance when using his own judgement (as indicated by a standard deviation of 323) and a higher degree of variance after a period of training as indicated by the standard deviation of 1070 (see Figure 10.5). An increase in consistency is therefore not evident for Subject 12 after the period of training.

10.3. The Qualitative Data

To recap briefly, the qualitative phase of data collection formed part of a mixed methods, explanatory sequential design and was undertaken to further examine issues that arose during the first phase of quantitative data collection. As outlined in the previous chapter, data were collected regarding how test participants approached a knapping task in two conditions: when using their own judgement (i.e., before any instruction) and after instruction (i.e., after viewing the video footage of expert knapper James Dilley).

For each test participant the following data were recorded for the two conditions: body position, core grip, hammerstone grip, blow height, and lateral movement of blow. The following categories account for all the choices made by the expert knapper and 12 test participants for body position, core grip, and hammerstone grip:

- Body Position: squatting, kneeling (both knees), kneeling (one knee), sitting (legs outstretched), sitting (cross legged)
- Core Grip: freehand (bottom grip), freehand (side grip), freehand (end grip), supported on thigh, supported on ground
- Hammerstone Grip: claw grip, side grip, three-fingered grip, spread-fingered grip

For the blow height and lateral movement of blow, an average was obtained from the 10 blows applied in each condition. Test participants' average choice of blow height and degree of lateral movement were then delineated into the following categories:

- Blow height: 0-10cm, 11-20cm, 21-30cm, 31-40cm, 41-50cm
- Lateral movement of blow: 0-2cm, 2-4cm, 4-6cm, 6-8cm, 8-10cm

For blow height all averages were rounded to the nearest whole number. For lateral movement all averages were rounded to 1 decimal place to allow them to be assigned to one of the defined categories. For example, an average lateral movement of 3.6 was assigned to the 2-4cm category, and an average lateral movement of 4.2 was assigned to the 4-6cm category. No average figures were left unattributed due to falling precisely on a boundary between categories (i.e., 2cm, 4cm, 6cm, and 8cm).

Lastly, the data also consist of field notes recording any comments made by test participants that further explicated their choices and motivations during the task. Subject-by-subject descriptions of the qualitative data will be presented below, with key trends subsequently summarised for the five main areas under examination (i.e., body position, core grip, hammerstone grip, blow height, lateral movement of blow).

10.4. Qualitative Data: Subject-By-Subject Description

10.4.0. The Expert Knapper

The footage of James Dilley was taken prior to the decision to include a second phase of testing. As a result, data relating to the hammerstone height and the lateral movement of his blows are unavailable for the expert knapper. It was possible, however, to gather data relating to body position, hammerstone grip and core grip from the recorded footage. James Dilley adopted a 'seated, legs outstretched' body position, a 'supported on thigh' core grip, and a three-fingered hammerstone grip.

10.4.1. Subject 1

Subject 1 was not available to engage in the second phase of testing.

10.4.2. Subject 2

Subject 2 initially adopted a 'seated, cross-legged' stance with the core held freehand (bottom grip). The hammerstone was held in a claw grip. The average height of her hammerstone blows was 24cm (standard deviation = 1.6), with an average lateral movement of 8.6cm (standard deviation = 1.7).

Prior to the task commencing Subject 2 asked ‘does it matter how I hold this?’ with reference to the hammerstone, to which the principal investigator replied that she should hold it however she feels would be most comfortable for the task. On viewing the footage of James Dilley, Subject 2 noted that he used a different body position and that she would ‘give it a go’ (i.e., try James Dilley’s body position). She further commented that she thought her initial cross-legged position was more comfortable. Note that the perception that she should adopt James Dilley’s stance stemmed entirely from her own interpretation of the standardised text, which does not explicitly state that test subjects should try and copy James Dilley’s body position.

After viewing the footage Subject 2 therefore changed her body position to a ‘seated, legs extended’ stance. Subject 2 changed her core grip from freehand (bottom grip) to supported on leg/thigh, and provided the following comment: ‘suppose it’s better, feels a little more accurate – could probably have done that how I was sitting before though’. The hammerstone grip remained unchanged and no comments were provided regarding this aspect of the task. After viewing the footage Subject 2 recorded an average blow height of 15cm (standard deviation = 2.3), with an average lateral movement of 2.9cm (standard deviation = 1.7).

10.4.3. Subject 3

Subject 3 initially adopted a kneeling stance (both knees) with the core held freehand (side grip). The hammerstone was held in a spread-fingered grip. The average height of his hammerstone blows was 48cm (standard deviation = 4.8), with an average lateral blow movement of 6.2cm (standard deviation = 1.9).

After viewing the video footage of James Dilley Subject 3 attempted to adopt the same body position, but noted that it 'feels like I'll fall backwards'. His original body position of kneeling on both knees therefore remained unchanged (a position in which he felt he had 'slightly more control').

With reference to his choice of a freehand side grip of the core, Subject 3 commented that he 'assumed that's how you held it', and he changed this core grip to supporting the core on his leg/thigh after viewing the video footage. The hammerstone grip remained unchanged and no comments were made regarding this aspect of the task. The average height of his hammerstone blows after viewing the video footage was 33cm (standard deviation = 2.3), with an average lateral blow movement of 6.5cm (standard deviation = 1.4).

10.4.4. Subject 4

Subject 4 initially adopted a kneeling stance (one knee) with the core held freehand (bottom grip). The hammerstone was held in a claw grip. The average height of her hammerstone blows was 20cm (standard deviation = 7.2), with an average lateral blow movement of 2.2cm (standard deviation = 1.0).

On viewing the footage Subject 4 commented that she 'can't sit like that – I won't get up again'; her body position therefore remained a kneeling stance (one knee). However, Subject 4 did change her core grip from freehand (bottom grip) to supported on her leg/thigh (no additional comments made). To facilitate this, Subject 4 swapped the knee on which she was kneeling after viewing the footage. For her original stance her left knee was on the floor, the core was held in her left hand, and she struck with her right hand.

After viewing the footage her right knee was placed on the floor, the core was supported on her left thigh with her left hand, and she struck with her right hand (Subject 4 was asked to turn to face the opposite direction as a result to allow the striking platform to be discernible on the footage). The hammerstone grip remained unchanged after viewing the footage (no additional comments made). After viewing the video footage the average height of her hammerstone blows was 10cm (standard deviation = 2.0), with an average lateral blow movement of 3cm (standard deviation = 1.3).

10.4.5. Subject 5

Subject 5 was not available to engage in the second phase of testing.

10.4.6. Subject 6

Subject 6 initially adopted a 'seated stance, legs fully extended', with the core held freehand (bottom grip). The hammerstone was held in a spread-fingered grip. The average height of his hammerstone blows was 28cm (standard deviation = 1.5), with an average lateral blow movement of 3.5cm (standard deviation = 1.4).

After the viewing the footage Subject 6 noted that he had 'got that spot on' with reference to his body position, core grip and hammerstone grip and was therefore happy to make no changes. The average height of his hammerstone blows was 28cm (standard deviation = 5.0), with an average lateral blow movement of 8.9cm (standard deviation = 2.8).

10.4.7. Subject 7

Subject 7 initially adopted a kneeling stance (one knee) with the core held freehand (side grip). The hammerstone was held in a 3-fingered grip. The average height of his hammerstone blows was 23cm (standard deviation = 2.7), with an average lateral blow movement of 4.6cm (standard deviation = 1.7).

Subject 7 chose not to make any changes in his body position after viewing the footage, commenting: ‘I’m good as I am thanks’. He similarly made no changes to his core grip or hammerstone grip, commenting: ‘All I gotta do is hit the dot again, right? Don’t reckon it’ll make much difference.’ After viewing the video footage the average height of his hammerstone blows was 24cm (standard deviation = 2.1), with an average lateral blow movement of 4.3cm (standard deviation = 1.7).

10.4.8. Subject 8

Subject 8 initially adopted a crouched stance with the core held freehand (end grip). The hammerstone was held in a spread-fingered grip. The average height of her hammerstone blows was 25cm (standard deviation = 7.2), with an average lateral blow movement of 3.7cm (standard deviation = 2.4).

After viewing the footage Subject 8 changed her body position to a kneeling stance (both knees) and changed her core grip to a freehand bottom grip. Despite attempts to prevent bias by using standardised text for instruction, Subject 8 commented that she ‘thought I had to crouch down’ for the task and noted that it ‘feels much better’ when she subsequently adopted a kneeling position. Regarding her choice of a freehand (end) core grip, Subject 8 commented that she 'knew I'd got that wrong after the first one [i.e., first blow] – it was really difficult to keep hold of it', and later commented that it was 'much better holding it underneath' with reference to adopting a freehand (bottom) grip.

Her hammerstone grip changed from a spread-fingered grip to a claw grip, but without further comment. The average height of her hammerstone blows after viewing the video footage was 24cm (standard deviation = 4.6), with an average lateral blow movement of 4.2cm (standard deviation = 1.6).

10.4.9. Subject 9

Subject 9 initially adopted a 'seated, cross-legged' stance with the core supported on the ground. The hammerstone was held in a 3-fingered grip. The average height of her hammerstone blows was 44cm (standard deviation = 1.6), with an average lateral blow movement of 7cm (standard deviation = 7.0).

Subject 9 noted that James Dilley's body position 'looks uncomfortable' and decided not to change her body position after viewing the video footage. Similarly, her core grip remained unchanged; she noted that holding the core on the floor meant it 'won't move when I hit it'. Subject 9 changed her hammerstone grip from a 3-fingered grip to a claw grip. Regarding this change, she noted that it 'seems closer' to the grip James Dilley used in the footage but that she 'didn't know if it worked any better.' After viewing the footage, the average height of her hammerstone blows was 49cm (standard deviation = 6.1), with an average lateral blow movement of 5.6cm (standard deviation = 2.8).

10.4.10. Subject 10

Subject 10 initially adopted a kneeling stance (one knee) with the core held freehand (bottom grip). The hammerstone was held in a side grip. The average height of his hammerstone blows was 50cm (standard deviation = 1.7), with an average lateral blow movement of 10.1cm (standard deviation = 1.5).

On viewing the footage Subject 10 expressed surprise at the body position of James Dilley, stating 'Oh, he sits like that'. He also noted that James used 'short, sharp hits' to strike the core. Subject 10 changed his body position after viewing the footage to a 'seated, legs extended' stance. His core grip and hammerstone remained unchanged and no comments were made regarding these aspects of the task. After viewing the footage the average height of his hammerstone blows was 35cm (standard deviation = 4.2), with an average lateral blow movement of 6.2cm (standard deviation = 1.3).

10.4.11. Subject 11

Subject 11 initially adopted a 'seated, cross-legged' stance with the core supported on the ground. The hammerstone was held in a 3-fingered grip. The average height of his hammerstone blows was 43cm (standard deviation = 1.8), with an average lateral blow movement of 2.3cm (standard deviation = 1.3).

After the viewing the footage Subject 11 noted that he was 'comfortable like this' and suggested he would lose control by stretching his legs out in a stance akin to James Dilley's. Regarding the core position, Subject 11 noted that, though he initially thought positioning the core on the ground would be best, he felt it was ‘perhaps easier to hit it [the dot on the striking platform]’ when holding the core freehand.

Subject 11 also considered his hammerstone grip, noting he was ‘happy with that’ (i.e., he was already using a 3-fingered grip like James Dilley). After viewing the footage, therefore, the body position and hammerstone grip of Subject 11 remained unchanged, while the core position changed from being supported on the ground to freehand (side grip). The average height of his hammerstone blows was 33cm (standard deviation = 5.4), with an average lateral blow movement of 3cm (standard deviation = 1.6).

10.4.12. Subject 12

Subject 12 adopted a ‘seated, legs extended’ stance with the core supported on his leg/thigh. The hammerstone was held in a 3-fingered grip. The average height of his hammerstone blows was 32cm (standard deviation = 1.6) with an average lateral blow movement of 10.2cm (standard deviation = 2.4).

After the viewing the footage Subject 12 commented that James Dilley’s body position ‘seems the best position’ and he remained in that position for the second series of 10 blows. Regarding the core position, Subject 12 changed this from supported on his leg/thigh to freehand (bottom grip). This represented a change from a core grip identical to James Dilley’s to one that differed from it after the video footage was viewed.

Unfortunately Subject 12 made no further comment regarding this change. Subject 12’s hammerstone grip remained unchanged and no comments were made regarding this after viewing the video footage, though he did note that the blows were ‘not all that hard’. After viewing the footage the average height of Subject 12's hammerstone blows was 23cm (standard deviation = 5.7), with an average lateral blow movement of 4.9cm (standard deviation = 3.7).

10.4.13. Subject 13

Subject 13 initially adopted a kneeling stance (both knees) with the core supported on her thigh. The hammerstone was held in a side grip. The average height of her hammerstone blows was 17cm (standard deviation = 2.9) with an average lateral blow movement of 1.5cm (standard deviation = 1.1).

On viewing the footage of James Dilley Subject 13 commented that his sitting position 'looked like an expert position'. After the footage Subject 13 changed her body position to a 'seated, cross-legged' stance. Subject 13 changed her core grip from being support on the thigh (akin to James Dilley's stance) to freehand (side grip), but without comment. The hammerstone grip remained unchanged. The average height of her hammerstone blows was 23cm (standard deviation 3.4), with an average lateral blow movement of 6.4cm (standard deviation 2.9).

10.4.14. Subject 14

Subject 14 initially adopted a kneeling stance (one knee) with the core held freehand (bottom grip). The hammerstone was held in a 3-fingered claw grip from the top. The average height of his hammerstone blows was 35cm (standard deviation = 2.9), with an average lateral blow movement of 7.4cm (standard deviation = 2.4).

On viewing the footage Subject 14 tried James Dilley's sitting position, but rejected it, commenting that it 'feels too wobbly'. He did, however, change his body position from kneeling on one knee to kneeling on both knees. Subject 14 changed his core grip from a freehand (bottom grip) to being support on the thigh, a position he noted was 'sturdier'. Regarding the support on the thigh core position, he also added that 'you wouldn't want to do it too much' after administering the second set of 10 blows, suggesting that it might cause bruising. The hammerstone grip for Subject 14 remained unchanged. After viewing the footage, the average height of her hammerstone blows was 40cm (standard deviation 1.8), with an average lateral blow movement of 6.4cm (standard deviation 1.2).

10.5. Qualitative Data: Summary of Results

10.5.1. Body Position

In total, 5 test participants (42%) chose to change their body position after viewing and reflecting on the footage, with 7 participants (58%) making no change (see Figure 10.28). The slightly higher number of participants deciding not to change their body position is notable given the indications from the qualitative data obtained through field notes. From the recorded comments this aspect of the task featured foremost in the reflections of the majority of subjects, and yet a slight majority chose to either disregard the footage of the expert knapper and retain their own stance, or to adopt a body position other than the 'seated, legs outstretched' stance used by James Dilley.

The recorded comments provide some insight as to the test participants' motivations: Subject 3, Subject 5 and Subject 11 all made comments that broadly concerned the degree of control they could maintain in the 'seated, legs outstretched' position, Subject 13 noted that it looked like an ‘expert’ position, and Subject 4 and Subject 9 had problems with the comfort of the position. In addition, for one of the five test participants (Subject 2) the data in the field notes suggests that the change to a ‘seated, legs outstretched’ body position was made reluctantly (perhaps in anticipation of the expected aims of the study).

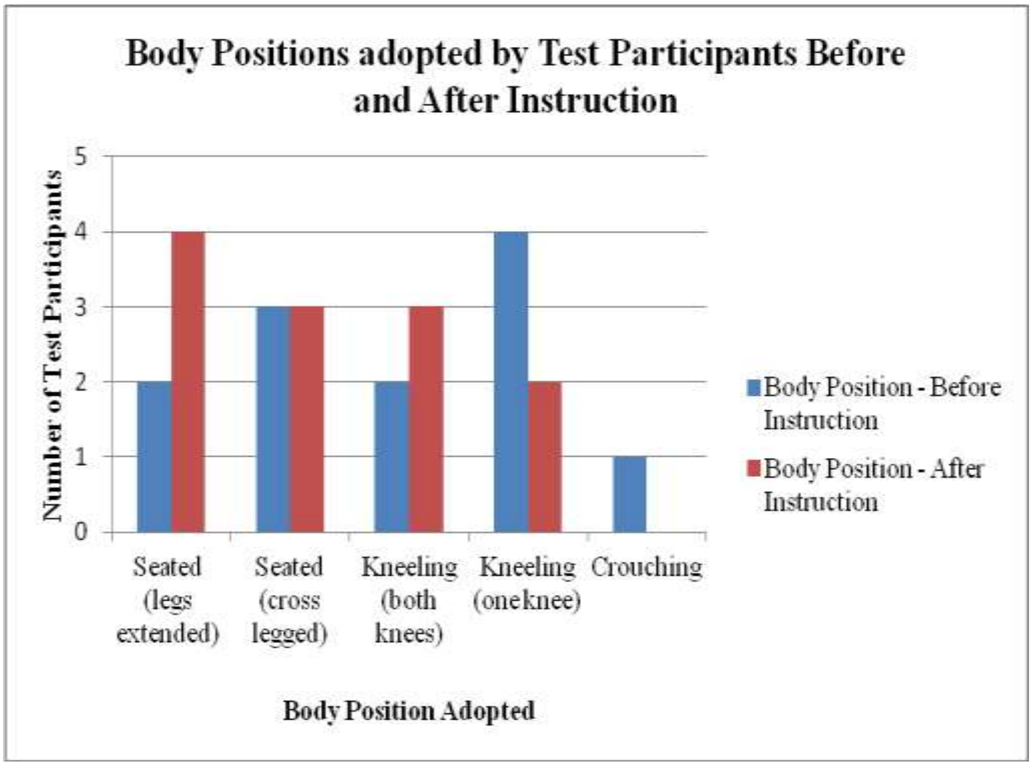


Figure 10.28: Total number of test participants adopted each body position before and after instruction.

The qualitative data are interesting in that they seem to indicate that body position is an area where novices feel confident in questioning, and also rejecting, information relating to ‘expert performance’, whether this is due to issues of control, confidence, or comfort. This point is further supported by the fact that 6 of the test subjects who chose not to adopt the ‘seated, legs outstretched’ position either before or after instruction contributed comments regarding body position, which gives a strong indication that they were fully cognisant of this aspect of the task.

10.5.2. Core Grip

Regarding core grip, a total of 8 test participants (67%) chose to change their grip after viewing and reflecting on the footage, with 4 participants (33%) making no change (see Figure 10.29).

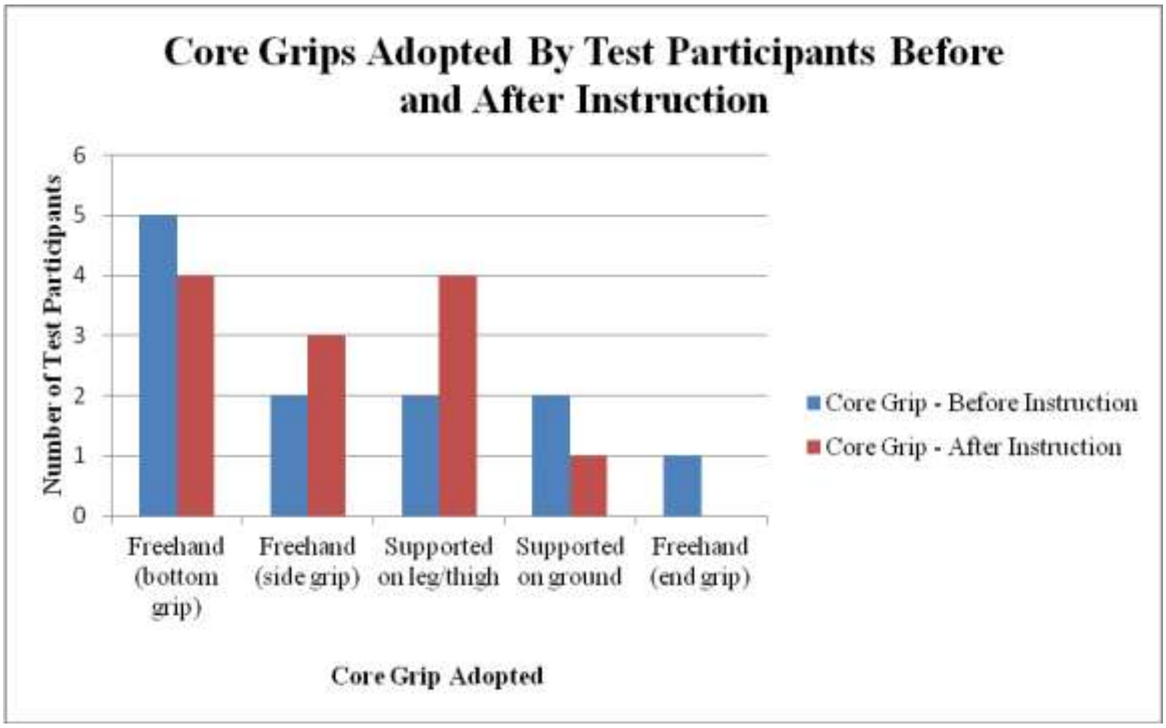


Figure 10.29: Total number of test participants adopting each core grip before and after instruction.

Unfortunately, the qualitative feedback was not as extensive as that collected for body position, with 4 of the 8 test participants who changed their core grip doing so without providing comment. For all four of the test participants who made comments regarding why they changed their core grip, however, it was clear that viewing the footage was the major contributing factor. Subject 2 and Subject 11 made comments to the effect that the 'supported on leg/thigh' grip felt more accurate, Subject 5 noted it felt more sturdy, and Subject 3 reacted in a way that made it clear he was influenced by the footage, though he didn't elaborate as to why (see section above regarding Subject 3). The mentioning of security/accuracy in relation to the 'supported on leg/thigh' grip is of added interest when one observes that 5 of the test participants who changed their core grip changed from one of the three freehand grips.

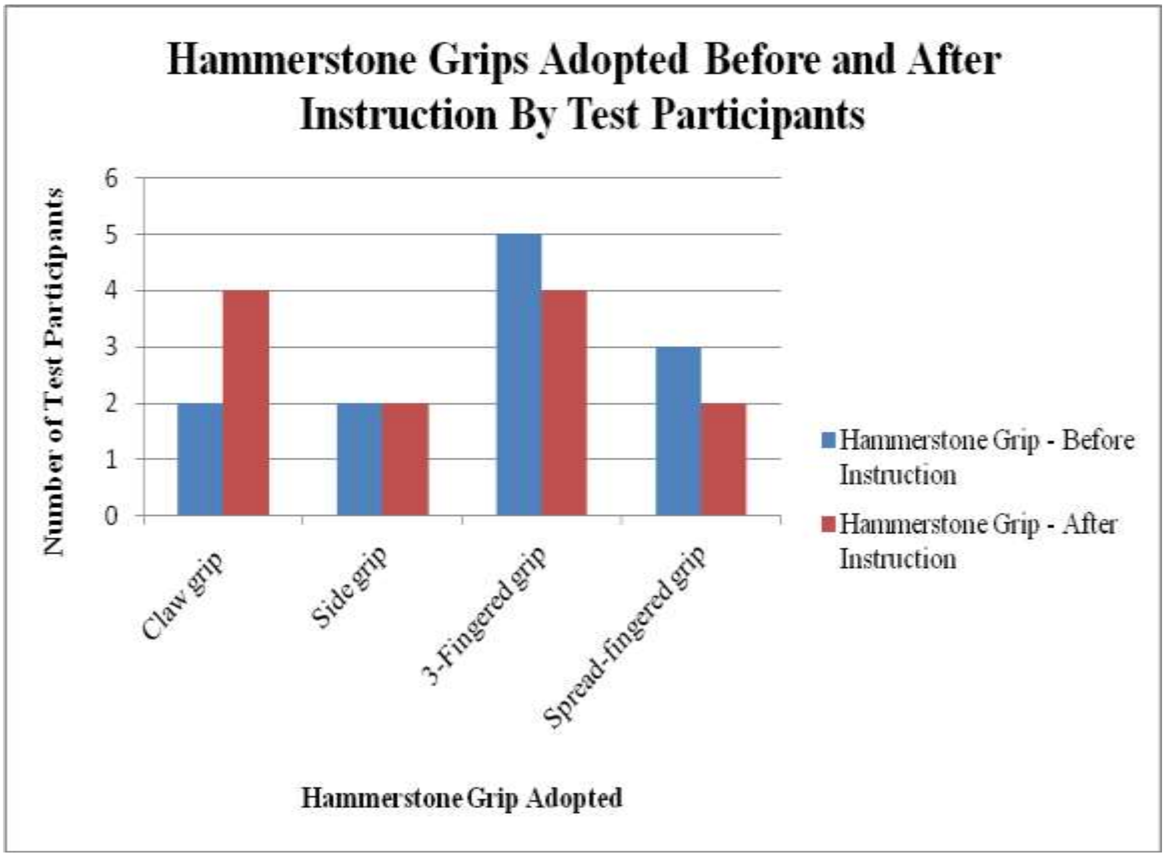


Figure 10.30: Total number of test participants adopting each hammerstone grip before and after instruction.

10.5.3. Hammerstone Grip

Regarding hammerstone grip, a total of 2 test participants (17%) chose to change their position after viewing and reflecting on the footage, with 10 participants (83%) making no change (see Figure 10.30). A significant number of test participants therefore chose to make no change in their hammerstone grip when compared to the other categories. A number of possible explanations could account for this trend. For example, the test participants may simply have been unaware of the nuances of the different hammerstone grips. Indeed, much like the different grips used in tennis, this may be an aspect of the task where a detailed description of the different possible grips was needed.

However, it is also notable that the two participants who did make change in this category made concerted efforts to make sure they were replicating James Dilley's hammerstone grip, so this aspect of the task cannot be assumed to be beyond the ability of novices *per se*. Another factor that may have contributed to this trend is the way the hammerstone grip presented in the standardised text. When asking test participants to reflect on the task, for example, they were asked to consider: 'how you sat, how you held the core and the hammerstone, how hard you struck and how straight or curved your swing was'. It may be the case that the wording invited participants to consider their body position first and foremost. Coupled with the fact that the body position represented a prominent part of the video footage, test participants may have focused on this to the detriment of other areas such as hammerstone grip.

10.5.4. Blow Height

Regarding the average blow heights used by test participants, after viewing the video footage 7 test participants reduced their average blow heights, 4 increased their average blow heights, and 1 displayed no change either way. A slight majority of test participants therefore reduced their average blow heights after viewing the footage of James Dilley, and data from the field notes suggests that viewing the footage may have contributed to this trend to an extent. Subject 2, for example, noted that James Dilley's blows were 'not very high, just quick', Subject 5 noted that he 'snaps it [the hammerstone blow]', Subject 10 noted that a 'short, sharp hit' was needed for the task, while Subject 12 commented that James' blows were 'not all that hard'.

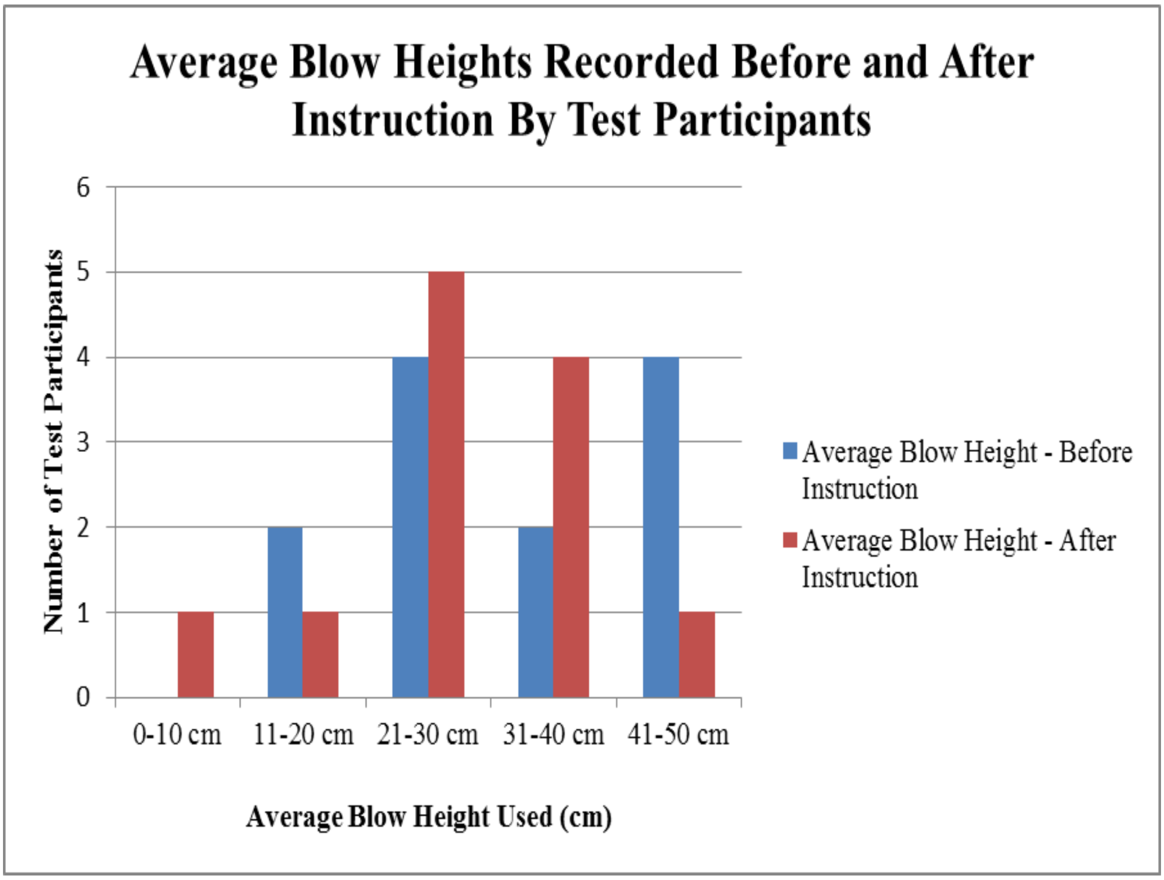


Figure 10.31: Average blow heights administered by test participants before and after instruction delineated into five categories.

Of those test participants who reduced their average blow height on viewing the footage, only 1 participant reduced it by between 1-5cm, 4 participants reduced it by between 6-14cm, and 2 participants reduced it by 15cm or more (see Figure 10.31). Of those test participants who increased their average blow height on viewing the footage, 3 participants increased it by between 1-5cm, 1 participant increased it by between 6-14cm, and no test participants increased it by 15cm plus.

These data appear to suggest, therefore, that the test participants who reduced their average blow height after viewing the footage did so to a greater degree than those who increased their average blow height: for the former the majority increased their average blow height by between 6-14cm, while for the latter the majority increased their blow height by between 1-5cm.

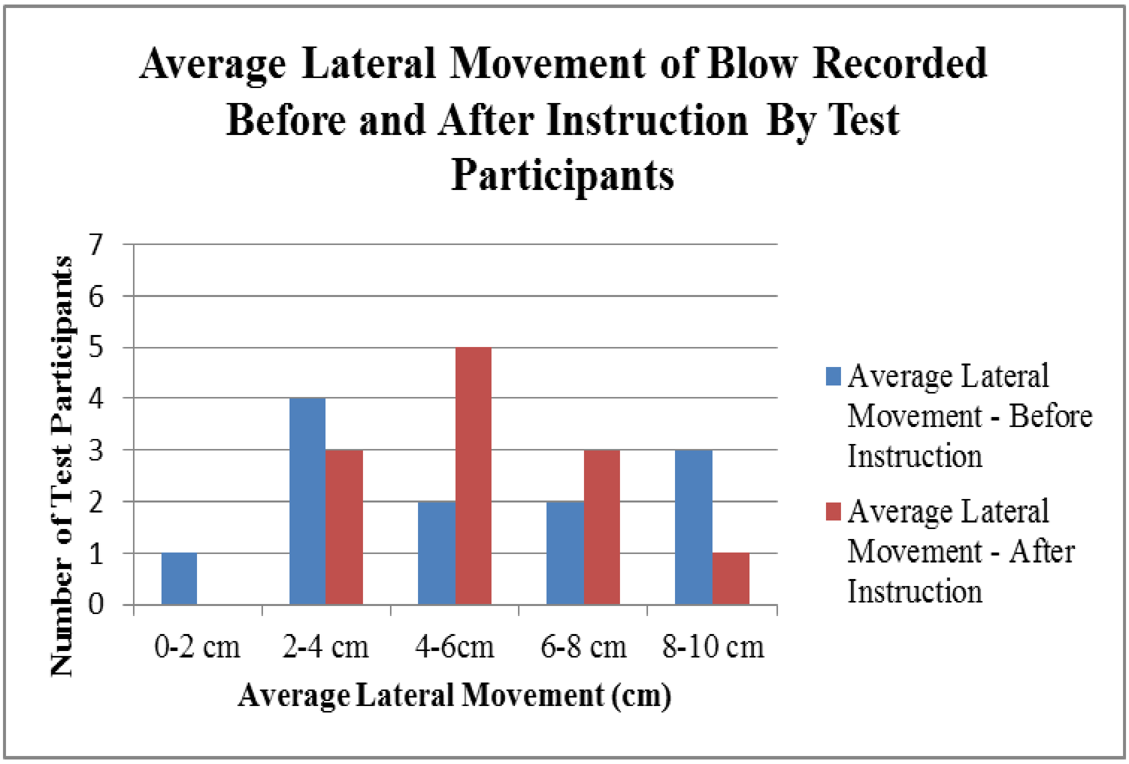


Figure 10.32: Average lateral movement of blow administered by test participants before and after instruction delineated into five categories.

10.5.5. Lateral Movement of Blow

Figure 10.32 shows average lateral movement of blow recorded by the 12 test participants before and after instruction split into 5 categories: 0-2cm, 2-4cm, 4-6cm, 6-8cm and 8-10cm. The largest change in average lateral movement was an increase of 5.7cm (Subject 2), and the smallest was 0.2 cm (Subject 9).

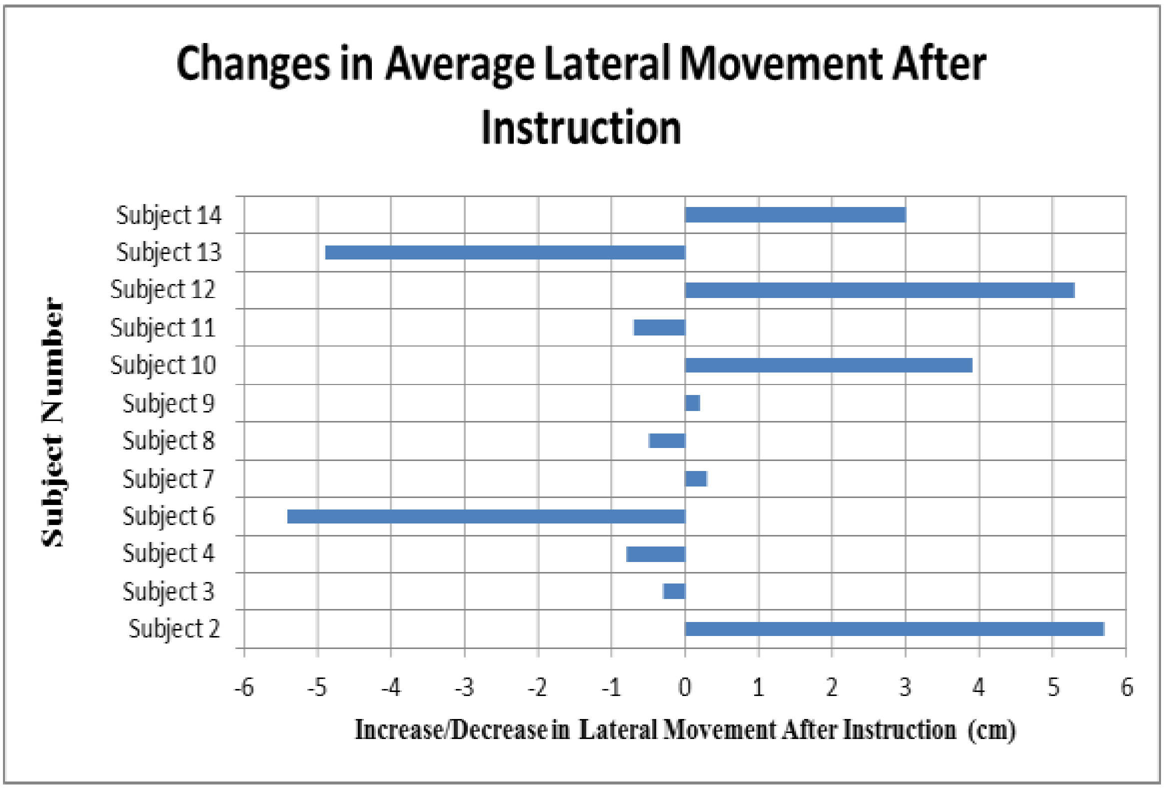


Figure 10.33: Changes in average lateral movement for the 12 test participants after instruction (cm).

After viewing the video footage 6 test participants reduced their average lateral movement, while 6 increased their average lateral movement. Of those test participants who reduced their average lateral movement of blow after viewing the footage, 2 participants reduced it by 0-2cm, 2 participants reduced it by 2-4cm, and 2 participants reduced it by 4-6cm (see Figure 10.33).

Of those test participants who increased their average lateral movement of blow after viewing the footage, 4 participants reduced it by 0-2cm, no participants reduced it by 2-4cm, and 2 participants reduced it by 4-6cm (see Figure 10.33). Unfortunately no test participants provided comments regarding this aspect of the task.

A point worth highlighting from this data is that for 6 of the test subjects a remarkable degree of consistency is maintained in the lateral movement exhibited over the course of testing. Though these test subjects recorded a low average lateral movement in the 0-2cm category, it is worth emphasizing the fact that all of them recorded a difference of less than plus or minus 1cm between the respective averages (see Figure 10.33).

10.6. Data Analysis/Synthesis

Alongside the raw qualitative data presented above, further insights can be gained from analysing and synthesising (where appropriate) the qualitative and quantitative data sets.

To recap, the qualitative phase aimed to answer two questions that arose from issues identified in the quantitative phase:

- Did the measuring equipment used impede performance in the quantitative phase?
- Was early stage self-learning evident?

To take the first these questions, for example, the qualitative data can provide insights in terms of identifying test subjects that adopted a body position or core grip that was not compatible with the use of the measuring equipment (as elucidated further below). Note, however, that this provides no indication as to whether the performance of test subjects was adversely affected as a result.

One means via which to further explore whether the measuring equipment had any implications for the performance of test subjects would be to revisit the quantitative data to assess how well these test subjects performed compared to others. If, for example, a total of 4 test subjects chose body positions incompatible with the measuring equipment, and those 4 test subjects produced the most erratic blow strengths in the quantitative phase (resulting in high standard deviation scores), the validity of the methodology, in terms of employing a large top-loading scale to record blow strengths, could be brought into question.

To address the second question regarding early stage self-learning, in contrast, requires further analysis of the changes made by test participants' in response to the instructional footage incorporating self-reported motivations.

10.6.1. Did the measuring equipment used impede performance in the first phase?

To examine whether the measuring equipment used may have impeded the performance of test subjects one needs to assess the qualitative data relating to body position, core grip and lateral movement of blow. Arguably, the data relating to hammerstone grip and blow height provide no additional insights regarding this area. Considering hammerstrone grip, for example, test subjects would have been able to select any of the four recorded grips in the first phase regardless of the type of striking platform presented. The testing equipment therefore presented no impediment to the completion of the task as a result.

Similarly, concerning blow height, though one could argue that the use of the measuring equipment presented a striking platform to test participants that would have been quite high when compared to some of the combinations of body and core positions adopted in the qualitative phase, it should also be noted that the equipment did not restrict the height to which the test participants could raise the hammerstone per se. It remains entirely plausible that the highest blow heights recorded in the qualitative phase (i.e., in the 40-50cm range) could have been similarly delivered in the quantitative phase. This assertion is supported by the fact that 6 of the highest average blow heights recorded (i.e., between 40-50cm) in the qualitative phase, either before or after instruction, were recorded by participants in the kneeling position with a freehand grip (which is a body position and core grip that presents a striking platform at approximately the same height as the measuring equipment in the quantitative phase).

To examine whether the measuring equipment used may have impeded test participants choice of preferred body position requires an initial delineation of the body positions used into two groups: those compatible with striking the top of the measuring equipment and those that are not. Arguably, kneeling (one knee), kneeling (two knees) and crouching are all compatible with striking the top of the measuring equipment used in the first phase without impediment. In contrast, the 'seated, legs extended' and 'seated, cross legged' body positions can be deemed incompatible with striking the top of the measuring equipment used in the first phase. These body positions would have been unduly awkward, presenting a striking platform that was too high (i.e., approximately chest height for most participants).

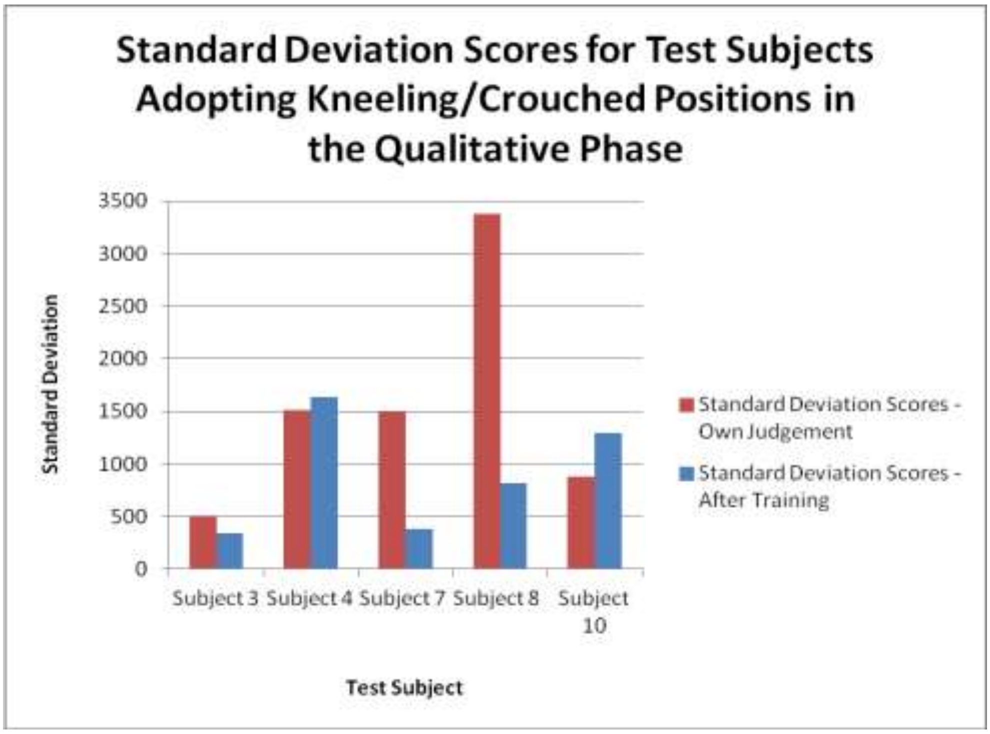
Given this delineation, it was observed that a total of 7 test participants (58%) adopted initial body positions that would have allowed the striking platform on the scale to be struck without hindrance. Of these 7 participants, 2 changed their body position after instruction to one that was not ideal for striking the platform on the scale. A total of 5 test participants (42%) adopted and maintained body positions that would have hindered the process of striking the platform on the scale. The data therefore appear to suggest that, before instruction, just under half of the test subjects would have been required to adopt a body position they would not have spontaneously chosen as the most comfortable for a knapping task.

One can gain further insight into this issue by referring back to the quantitative data. A comparison of the consistency (as indicated by the standard deviation scores) of the 5 test participants who elected for, and maintained, a seated position in the qualitative phase with the 5 test participants who adopted a kneeling or crouched position is potentially informative[58]. One could posit, for instance, that if the adoption of a kneeling stance in the first phase represented an impediment for the 5 test participants who subsequently preferred a seated position in the second phase, then this should be reflected in their performance. However, arguably no such trend is evident.

Figure 10.34 shows the standard deviation scores for test participants in the first phase delineated into two groups: those that preferred kneeling in the qualitative phase and those that preferred to be seated. When the standard deviation scores for test participants applying blows using their own judgement and after instruction are amalgamated (see Table 10.3), the data indicate no discernible difference in terms of the consistency

[58] This comparison excludes the two test participants who did not participate in the first phase (i.e., Subjects 13 and 14).

displayed. A high level of consistency (i.e., a standard deviation score between 0 and 500) was evident in 3 standard deviation scores for test participants who preferred kneeling in the qualitative phase and 3 standard deviations scores for those who preferred sitting in the qualitative phase. A reasonable degree of consistency (i.e., a standard deviation score between 500 and 1000) was evident in 2 standard deviation scores for those who preferred kneeling in the qualitative phase and 3 standard deviation scores for those who preferred sitting in the qualitative phase.



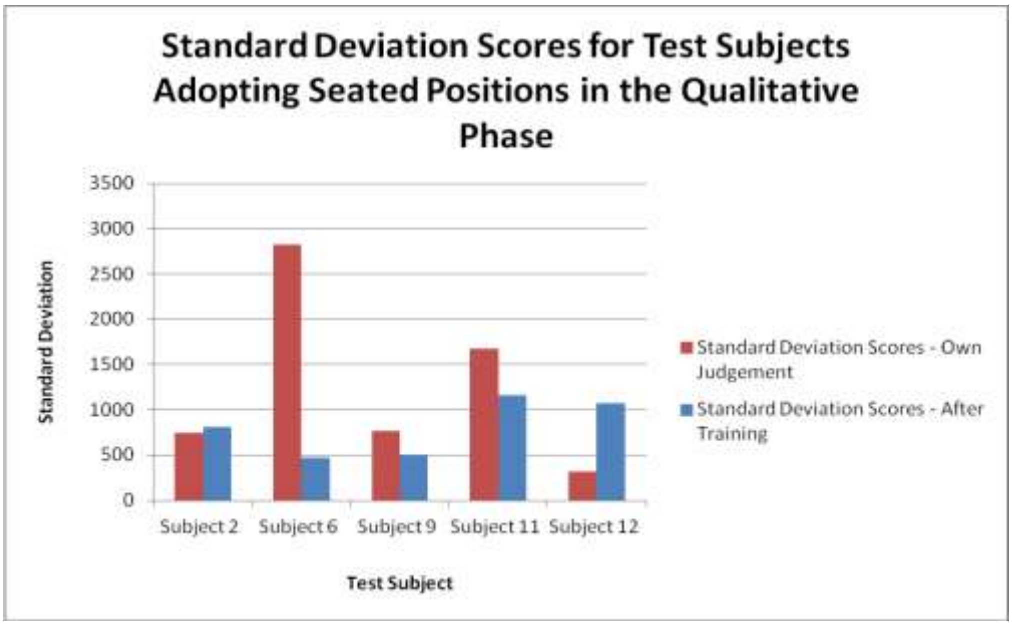


Figure 10.34: Bar chart displaying the standard deviation scores for test participants in the first phase of quantitative data collection. *Top:* Standard deviation scores from the first phase for test participants who preferred a kneeling or crouched position in the qualitative phase. *Bottom:* Standard deviation scores from the first phase for test participants who preferred a seated position in the qualitative phase.

Standard Deviation Recorded	Test subjects who preferred Kneeling Position Qualitative Phase	Test subjects who preferred Seated Position in the Qualitative Phase
0-500	3 (30%)	3 (30%)
500-1000	2 (20%)	3 (30%)
1000 +	5 (50%)	4 (40%)

Table 10.3: Total number of test participants displaying a high level of consistency (i.e., SD = 0-500), a reasonable level of consistency (SD = 500-1000) and a low level of consistency (SD = >1000). The data include 2 standard deviation scores for each test participant under the two conditions used in the first phase (i.e., own judgement and after instruction)

Finally, a low degree of consistency (i.e., a standard deviation score of greater than 1000) was evident in 5 standard deviation scores for those who preferred kneeling in the qualitative phase and 4 standard deviation scores for those who preferred sitting in the qualitative phase.

No notable trend is evident, therefore, to suggest that the test participants who preferred a seated position in the qualitative phase performed comparably worse in the first phase. These findings suggest that it is unlikely that the kneeling/crouched body positions used in the first phase of data collection had an adverse effect on the integrity of the data, despite the fact that some test participants would have preferred a seated body position. In order to make the data collection process as rigorous as possible, however, it would be prudent to offer different body position options to test participants by modifying the equipment or the set up to allow various body positions to be adopted.

Concerning core grip, one can similarly perform an initial delineation of the grips used into two groups: those compatible with striking the top of the measuring equipment and those that are not. In this instance, the grips where the core is secured, preventing any movement, can be considered analogous to the striking platform presented in the first task.

Conversely, the three freehand grips (i.e., end grip, side grip and bottom grip), where the core can be turned towards the source of the blow, cannot be considered analogous to the striking platform presented in the first task.

One area of interest reading potential unwitting biases in the first phase of testing concerns whether the majority of test subjects spontaneously chose a freehand grip for the knapping task in the qualitative phase. If this were the case, one could surmise that test participants may have been operating outside their comfort zone when applying blows to the measuring equipment in the first phase. As a result, a period of prior instruction in knapping may have been required to familiarise them with the ideal way to hold a core.

The data support this view to an extent, with 8 test participants choosing a freehand grip in the first instance. A second area of interest, however, concerns whether the proposed training period prior to the task in the first phase would have elicited the desired response (i.e., a change from a freehand grip to a supported grip). This trend was evident for only 4 of the 8 test participants who initially chose a freehand grip. Given the trends identifiable in the qualitative data, therefore, one could question the utility of a period of prior training for test participants in the first phase. Indeed, it is also worth adding that 3 test participants changed from a supported grip to a freehand grip after instruction.

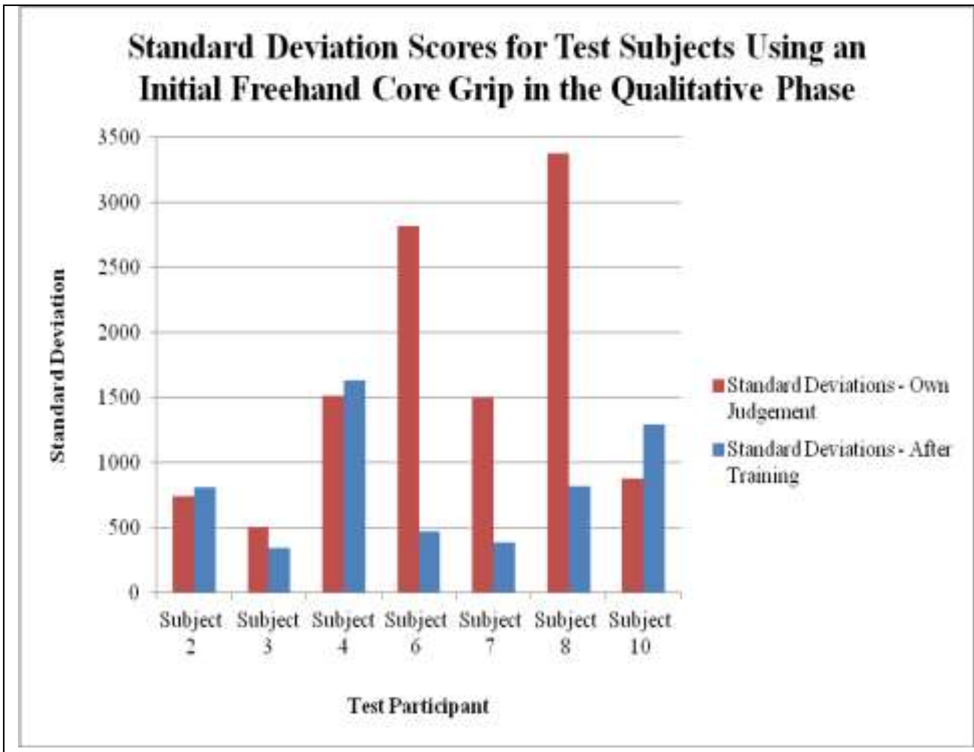
The disparate choices made by the test participants in this area, however, provide further support to the view that more flexibility in test design may be needed in the future. For example, one could incorporate mobile measuring equipment that more closely replicates the typical size and shape of a core which would allow the participants adopt a freehand grip, or similarly rest on their thigh or the floor (see, for example, Rolian et al (2011)).

Another area that requires consideration concerns whether the measuring equipment used in the first phase affected the test participants' ability to consistently apply blows to the striking platform. Again, one can gain further insight into this issue by referring back to the quantitative data. A comparison of the consistency (as indicated by the standard deviation scores) of 7 of the test participants who initially opted for a freehand core grip in the qualitative phase with 3 of the test participants who initially opted for a supported core grip is potentially informative[59]. Again, one could posit that if the necessity of striking the scale with a supported-type core grip in the first phase represented an impediment for the 7 test participants who subsequently preferred a freehand grip in the second phase, then this should be reflected in their performance. Again, however, no such trend is evident.

Figure 10.35 shows the standard deviation scores for test participants in the first phase delineated into two groups: those that preferred an initial freehand core grip in the qualitative phase and those that preferred a supported grip. When the standard deviation scores for test participants applying blows using their own judgement and after instruction are amalgamated (see Table 10.4), the data indicate no discernible difference in terms of the consistency displayed.

A high level of consistency (i.e., a standard deviation score between 0 and 500) was evident in 4 standard deviation scores for those who preferred a freehand core grip in the qualitative phase and 2 standard deviation scores for those who preferred a supported grip.

[59] This comparison excludes the two test participants who did not participate in the first phase (i.e., Subjects 13 and 14).



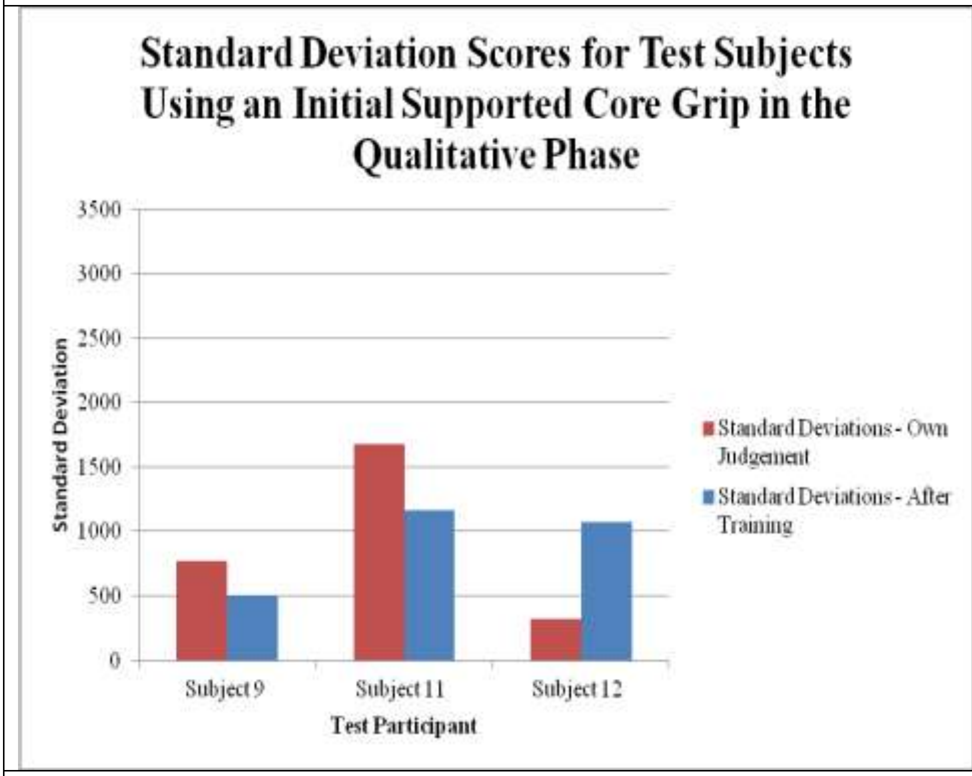


Figure 10.35: Bar chart displaying the standard deviation scores for test participants in the first phase of quantitative data collection. *Top:* Standard deviation scores from the first phase for test participants who preferred an initial freehand core grip in the qualitative phase. *Bottom:* Standard deviation scores from the first phase for test participants who preferred an initial supported grip in the qualitative phase.

A reasonable degree of consistency (i.e., a standard deviation score between 500 and 1000) was evident in 4 standard deviations scores for who preferred a freehand core grip in the qualitative phase and 1 standard deviations score for those who preferred a supported grip.

Finally, a low degree of consistency (i.e., a standard deviation score of greater than 1000) was evident in 6 standard deviation scores for who preferred a freehand core grip in the qualitative phase and 3 standard deviation scores for those who preferred a supported grip in the qualitative phase. To further illustrate this point, when viewing the percentages of standard deviation scores in the respective categories (see Table 10.4) it is notable that they are very similar, despite the fact that the number of standard deviation scores contributing to the 'supported grip' category is less than half that of the 'freehand' category (which, one could argue, would present opportunity for outliers to affect the freehand group).

Standard Deviation Recorded	**Adopted Initial Freehand Grip in the Qualitative Phase**	**Adopted Initial Supported Grip in Qualitative Phase**
0-500	4 (28.5%)	2 (33%)
500-1000	4 (28.5%)	1 (17%)
1000 +	6 (43%)	3 (50%)

Table 10.4: Total number of test participants displaying a high level of consistency (i.e., SD = 0-500), a reasonable level of consistency (SD = 500-1000) and a low level of consistency (SD = >1000). The data include 2 standard deviation scores for each test participant under the two conditions used in the first phase (i.e., own judgement and after instruction)

No notable trend is evident, therefore, to suggest that the test participants who preferred a freehand grip in the qualitative phase performed comparably worse in the first phase. Again, I would argue that these findings suggest that it is unlikely that the equipment used in the first phase of data collection had an adverse effect on the integrity of the data.

A further comparison of potential interest that can be made concerns the degree to which the different core grips affected the degree of lateral movement evident in blow trajectories. Again, one can retain the distinction made above between core grips that are consistent with striking the scale (i.e., all supported grips) and those not consistent with striking the scale (i.e., all freehand grips). Given that a freehand grip allows the test subject to tilt the core toward the direction of the blow, while a supported grip does not, one could posit that different blow trajectories may be required to apply blows for the different grips. If this trend is evident, one could conclude that the requirement to adjust the lateral movement of applied blows for supported grips indicates an impediment being present.

Seemingly, however, the data do not support the conclusion that different core grips necessitate different blow trajectories. A total of 7 test subjects made a change in their core grip either from freehand to supported, or from supported to freehand[60]. Of those that changed from freehand grips to supported grips, 2 subjects (Subjects 3 and 4) exhibited only small shifts (i.e., in the 0-2cm range) in the average lateral movement of blow after changing core grip and 2 subjects (Subjects 2 and 13) exhibited quite a high shift (i.e., in the 4-6cm range) (see Tables 10.5 and 10.6). Of those that made the converse change from a supported grip to a freehand grip, 1 subject (Subject 11) exhibited a small shift (i.e., in the 0-2cm range) in average lateral movement when changing core grip, 1 subject (Subject 14) exhibited a medium shift (i.e., in the 2-4cm range) and 1 subject (Subject 12) exhibited a high shift (i.e., in the 4-6cm range) (see Tables 10.5 and 10.6).

[60] Since the data comparisons here do not draw on the quantitative results, Subjects 13 and 14 are included.

	Subject 3	Subject 4	Subject 7	Subject 8	Subject 9	Subject 11
Average Lateral Movement Before Instruction (cm)	6.2	2.2	4.6	3.7	5.8	2.3
Average Lateral Movement After Instruction (cm)	6.5	3	4.3	4.2	5.6	3
Plus/minus difference in average lateral movement (cm)	-0.3	-0.8	+0.3	-0.5	+0.2	-0.7

Table 10.5: Table showing average lateral movements in centimetres for 6 test subjects who maintained a high degree of consistency.

	Subject 2	Subject 6	Subject 10	Subject 12	Subject 13	Subject 14
Average Lateral Movement Before Instruction (cm)	8.6	3.5	10.1	10.2	1.5	7.4
Average Lateral Movement After Instruction (cm)	2.9	8.9	6.2	4.9	6.4	4.4
Plus/minus difference in average lateral movement (cm)	-5.7	+5.4	-3.9	-5.3	+4.9	-3

Table 10.6: Table showing average lateral movements in centimetres for 6 test subjects who maintained a low to medium degree of consistency.

For those test subjects who chose a freehand grip and maintained it after instruction, 2 subjects (Subjects 7 and 8) exhibited small shifts (i.e., in the 0-2cm range) in the average lateral movement of blow, 1 subject (Subject 10) exhibited a medium shift (i.e., in the 2-4cm range) and 1 subject (Subject 6) exhibited a high shift (i.e., in the 4-6cm range) (see Tables 10.5 and 10.6). Finally, only Subject 9 chose and maintained a supported grip, exhibiting only a small shift (i.e., in the 0-2cm range) in average lateral movement.

Given the apparent lack of any evident trend in the data suggesting a link between increased or decreased lateral movement and changes in core grip, one cannot therefore conclude that the measuring equipment used in the first phase introduced unnecessary constraints on the degree of lateral movement that could be applied when striking a blow.

10.2. Was early stage self-learning evident?

The second aim of the qualitative phase of data collection was to examine whether self-learning influenced test participants' behaviour during the kinds of short testing episodes utilised in the first phase. Though the qualitative data relating to body position, core grip, blow height and lateral movement of blow provided a degree of insight into this area, the data relating to hammerstone grip provided little additional data. As noted above, this area of the task elicited no insightful comments from the test participants and only 2 of the 12 test participants chose to make changes to their hammerstone grip after instruction. Rather than evidencing a lack of self-learning, however, I would argue that the lack of changes in hammerstone grip can be attributed to factors noted previously (i.e., the lack of prominence of hammerstone grip in the footage and standardised text, and test participants' being unaware of the nuances of the various possible grips).

Considering body position, and as noted above, the qualitative data recorded 5 test participants changing their body position after viewing the video footage. Interestingly, the data also suggests that some test participants who chose not to make a change were still displaying self learning. A number of test subjects, for instance, noted James Dilley's stance, but declined to change, citing reasons of control, confidence, or comfort. Similarly, for core grip, the majority of test subjects (8 in total) chose to change their grip after viewing and reflecting on the footage. Of those 8 test subjects, 4 provided further qualitative feedback on why they changed, cited reasons of accuracy and stability.

Body position and core grip therefore represent two areas where evidence of self-learning is present, though by no means ubiquitous. A more comprehensive data set for these areas may have been possible through further data collection, possibly in the form of a follow questionnaire probing test subjects motivations regarding various choices.

Regarding blow height, I would argue that the qualitative data suggests that viewing the footage of James Dilley did indeed prompt test participants to reflect on their own blow delivery and adjust the blow height used accordingly. This is a trend, however, that was also identifiable in the quantitative data, where the majority of test participants reduced their average blow strength in response to the instruction provided. Unfortunately, one cannot establish with any confidence from the data whether using video footage as a method of instruction was more or less efficient than the method used in the first phase (i.e., a pie-slice indicator and verbal instruction). What the qualitative data add to the quantitative data, however, is an indication, as garnered from the participants' comments noted above, that self-learning is present when judging blow height and blow strength within the short, time constrained tasks used in both phases.

Regarding average lateral movement of blow, the data collected had the potential to provide further insights into the first phase, though there are also accompanying limitations. As stated previously, little qualitative feedback was provided regarding this aspect of the task, and one cannot therefore say whether the lateral movement was a conscious consideration. Despite this fact, one can still make some inferences regarding the presence or absence of self-learning to a degree. For example, one could infer that at least some of the 6 test participants who maintained a high degree of consistency (i.e., a shift of between 0-2cm) for the average lateral movement of blow over the two conditions did not exhibit self-learning in this area of the task. This inference can be made on the basis that, despite the high degree of consistency exhibited by the 6 test participants between the two conditions, they display a range of lateral movements ranging from a high of 6.2cm to a low of 2.2cm (see Table 10.5).

Using their own judgement, Subject 3 and Subject 9 applied blows exhibiting a high average lateral movement (6.2cm and 5.8cm respectively); Subject 7 and Subject 8 applied blows using their own judgment that exhibited a medium average lateral movement (4.6cm and 3.7cm respectively); and Subject 4 and Subject 11 applied blows using their own judgement that exhibited a low average lateral movement (2.2cm and 2.3cm respectively).

Given the high degree of consistency exhibited (the average change in later movement of blow for these 6 test subjects were all below 0.8cm) one can infer that at least some of the 6 test subjects did not exhibit self-learning in this area. This stands to reason, because James Dilley's average lateral movement, though not recorded in the first phase, would also have fallen into one of the categories used (i.e., 0-2cm, 2-4cm, and 4-6cm) or even exceeded them. Consequently, at least some of the 6 test subjects discussed began by using a lateral blow movement that was not consistent with the expert knapper, and subsequently maintained that degree of movement despite an opportunity to correct the error through self-learning[61].

For the remaining 6 test participants, sizeable changes (i.e., maximum shift of 5.7cm and minimum shift of 3cm) were evident in their average lateral movement of blow after instruction (see Table 10.6.4). In this case, one could argue that if test participants were exhibiting the early stages of self-learning in response to the footage of James Dilley an identifiable trend would be present. For example, if the instructional footage showed a high degree of lateral movement in James Dilley's blows, one would expect the averages for the test subjects to increase after viewing, and vice versa if the footage showed a low degree of movement by the expert knapper. Again, however, the data appear inconclusive. Of the 6 test subjects, 4 decreased their average lateral movement after instruction and 2 increased their average lateral movement (see Table 10.6.4).

Verifying whether the decreased averages from the 4 test subjects represents a genuine trend resulting from early stage self-learning, however, would require further supporting evidence, either in the form of verbal feedback from test participants regarding what motivated their change in behaviour, or by comparing the data with the average lateral movement recorded James Dilley. The latter might provide at least some indication as to whether the test subjects were adopting lateral blow movements similar to those of the expert knapper after instruction. Unfortunately, neither of these supporting data sources are available to clarify this point.

[61] It's possible, of course that the test subjects simply did not attend to this aspect of the task. If this was the case, however, one could similarly infer that self –learning was not taking place.

10.7. Conclusion

In conclusion, this chapter presented the results of a mixed methods, explanatory sequential design that consisted of two distinct phases: a first phase of quantitative data collection examining test participants judgment of blow strength, followed by second phase of qualitative data collection examining test participants interpretation of various aspects of a knapping task, including body position, core grip, hammerstone grip, blow height and the lateral movement of blow. The key findings of the quantitative and qualitative data sets can be summarised as follows.

The key findings of the quantitative data related to two main areas: the first, as a consequence of the methodology adopted, was that the test subjects would overestimate the blow strength required when using their own judgement; the second was the working hypothesis that test participants will display better judgement (determinable through greater consistency) when applying blow strengths that are equivalent to those typically encountered in a knapping task, as opposed to those blow strengths that seem intuitively appropriate.

Regarding the former, it was observed that of the 12 test participants 9 displayed reduced average blow strengths after training when compared to their own judgement, while 3 produced the reverse result. For the 9 test participants who reduced their average blow strength, however, significant variation was evident in terms of the degree of reduction recorded (this issue will be discussed further in Chapter 11).

Regarding the latter, it was observed that 7 of the 12 test participants performed in accordance with the predicted directional hypothesis (i.e., more variance was evident in blows applied when using their own judgement than after an episode of training). However, as will be discussed further in Chapter 11, the variance evident between the two test conditions for the 7 test participants who performed in accordance with the predicted directional hypothesis was far from uniform; only 3 test participants' scores could be interpreted as robustly concurrent with the directional hypothesis.

The key findings of the qualitative data related to two main areas: whether the measuring eqipment from the first phase presented an impediemtn to test subjects, and whether early stage self-learning was evident.

Regarding the former, the analysis presented above identified no notable trend to suggest that the test participants who preferred a seated position in the qualitative phase performed comparably worse in the first phase. Similarly, further analysis of the qualitative data did not identify any trends indicating that the test participants who preferred a freehand grip in the qualitative phase performed comparably worse in the first phase. One can therefore conclude that the measuring equipment used in the first phase of data collection had no adverse effect on the integrity of the data in terms of body position or core grip.

Regarding the latter, further analysis of the qualitative data provided good indications that body position, core grip, and blow height represent areas where evidence of self-learning is present, though by no means ubiquitous, while no identifiable trend was present to indicate early stage self-learning in terms of lateral movement of blow. Finally, it was noted that a more comprehensive data set for these areas could have been obtained via methodological improvements (e.g., a follow questionnaire probing test subjects motivations regarding various choices).

Chapter 11: Discussion and Conclusions

11.1. Introduction

The aim of Chapter 11 is to bring together the main findings of the thesis as a whole. It broadly consists of three sections: a discussion section focusing on the evaluation of the main findings of the data obtained, a section discussing the limitations of the study together with the implications for future research in this area, and the overall conclusions of the research.

The discussion section will provide a critical evaluation of the quantitative and qualitative results. The quantitative data will be evaluated to determine whether the two predicted trends were evident: i.e., that the test subjects will overestimate the blow strength required when using their own judgement (and reduce it in response to training), and that a greater degree of consistency will be evident when test subjects use blow strengths that are appropriate for the task. The qualitative data will be evaluated to see whether the equipment used in the quantitative phase presented an impediment to test subjects, and whether self learning was evident in the short time-frames used.

The limitations of the study will also be considered, particularly with reference to how future studies in this area could be improved. Consideration will be given to the cohort size, the addition of more phases of testing, the incorporation of more knapping variables, the targeting of specific demographics, and improvements to the methodology employed. Finally, the conclusion will bring together the findings of the thesis as a whole.

11.2. Discussion: The Quantitative Data

The main aim of the quantitative phase of data collection was to explore whether two trends were evident in the results obtained: first, whether test participants overestimated the blow strength required under their own judgement and applied blows suitable for the task after training and, second, whether the test participants exhibited the trend predicted in the directional hypothesis (i.e., displaying an increase in consistency after training).

11.2.1. Predicted Trend #1

Of the 12 test participants 9 displayed reduced average blow strengths after training when compared to their own judgement, while 3 produced the reverse result (Subject 3, Subject 6, Subject 9). It is interesting to note that all 3 test subjects who produced a lower average blow strength when using their own judgement were introduced to the training episode first. Despite attempts to minimise the introduction of bias into the methodology, therefore, it is possible that the guidance provided during training led to conscious or unconscious suppositions regarding the test which may have influenced their subsequent interpretation of the task-appropriate blow strength required. For instance, the exposure to the ‘pie slice’ indicator as a guide to accuracy may have caused test subjects to attempt to similarly focus the blows applied using their own judgement.

Further analysis of the data, however, suggests that a variety of scenarios were discernible in terms of how the average scores were produced. For example, four participants produced results exhibiting the predicted trend of overestimating the required blow strength when using their own judgement, while subsequently reducing their blow strengths to coincide approximately with those indicated during the period of training

(Subject 1, Subject 5, Subject 11, Subject 12). Four participants showed the predicted trend of overestimating the required blow strength when using their own judgement, while only displaying a slight reduction in the blow strengths used after training (i.e., the blow strengths applied where not within the range used by James Dilley) (Subject 2, Subject 7, Subject 8, Subject 10). Two participants used blow strengths similar to those used by James Dilley both when using own judgement and after a period of training (Subject 3, Subject 9). Finally, for two of the test participants (Subject 4, Subject 6) it was difficult to discern a pattern in this respect.

Though the majority of test subjects performed as predicted, these results do suggest that there were discrepancies in terms of how well individual test participants performed in the task. The four test participants who overestimated the blow strength required and subsequently failed to reduce the blows strength used after training, as well as the two participants for whom no discernible pattern was evident, are particularly problematic for interpreting the results as a whole. Indeed, though the qualitative data suggests that self-learning is feasible in a knapping task using short time frames (an issue discussed further below), the variations evident in performance suggests that the novices differed in terms of how well they adapted to the presented task.

11.2.2. Predicted Trend #2

Regarding the second predicted trend, 7 of the 12 test participants performed as the directional hypothesis predicted: i.e., more variance was evident in blows applied by test participants when using their own judgement than when they were attempting to apply blows within the range indicated during the training sessions (Subject 1 (if outlier disregarded), Subject 3, Subject 5, Subject 6, Subject 7, Subject 9, Subject 11). In contrast, 5 test subjects exhibited the reverse trend (Subject 2, Subject 4, Subject 8 (if outliers disregarded), Subject 10, Subject 12).

Again, a variety of scenarios were discernible in terms of the standard deviations exhibited. For 3 of the test participants (Subject 6, Subject 7 and Subject 11) the variance exhibited between the predicted trend and the scores in the respective conditions were sizeable. For four of the test participants (Subject 1 (outliers removed), Subject 3, Subject 5 and Subject 9) the variance conformed to the predicted trend, but the scores in the respective conditions were close together (i.e., a minimum difference of 31 and a maximum difference of 166 in terms of standard deviation). Two test subjects (Subject 2 and Subject 8) showed the reverse of the expected trend, though again with the respective scores in the two conditions were close together (a minimum difference of 104 and a maximum of 163 in terms of standard deviation). Finally, three test subjects exhibited the reverse of the expected trend with sizeable difference between the respective standard deviations (Subject 4, Subject 12, and Subject 10).

Overall, therefore, the results were consistent with the predictions of the directional hypothesis in that test participants displayed better judgement (determinable through greater consistency) when applying blow strengths that are equivalent to those typically encountered in a knapping task, as opposed to those blow strengths that seem intuitively appropriate. Given the degree of variation in the breakdown provided above, however, one could question whether the evident trend is more a result of adopting a broad delineation (i.e., more consistent or less consistent). If, for example, one required a sizeable difference between the respective standard deviation scores then only 3 test subjects would have produced results consistent with the directional hypothesis, with 9 producing results consistent with the null hypothesis. The possible influence of confounding variables is also difficult to discount, particularly given the informal observations that motivated the incorporation of a second phase of qualitative data collection.

11.3. Discussion: The Qualitative Data

The main aim of the qualitative phase of data collection was to explore two main issues that arose in the quantitative phase. The first concerned a possible confounding variable in the form of the measuring equipment used (i.e., the platform on the top loading scale). If, for example, test subjects were necessarily adopting body positions in the first phase that they would otherwise not have adopted, one could posit that their ability to deliver a hammerstone blow consistently may have been impeded, and the validity of the quantitative data could be questioned as a result.

The second issue concerned whether self-learning was a plausible influencing factor during the short testing episodes used in the first phase, and whether it could have influenced the degree of consistency exhibited in the first phase by test participants as a result. One area of particular interest here was whether test participants responded differently to the 'abstract' method of instruction used in the first phase (i.e., a pie-slice indicator affixed to the dial of the scale) when compared to the video footage used in the second phase. These two issues will be considered below with reference to the qualitative data.

11.3.1. Did the measuring equipment used impede performance in the first phase?

The qualitative data, coupled with the additional analysis and cross-comparisons with the quantitative data provided in Chapter 10, identified no notable trend to suggest that the test participants who preferred a seated position in the qualitative phase performed comparably worse in the first phase. Similarly, further analysis of the qualitative data provided no indication that test participants who chose a freehand grip in the qualitative phase performed comparably worse in the quantitative phase. I would argue that provides a strong validation of the methodology employed, and that the measuring equipment used in the first phase of data collection had no adverse effect on the integrity of the data in terms of body position or core grip.

11.3.2. Was early stage self-learning evident?

The second aim of the qualitative phase of data collection was to examine whether self-learning influenced test participants' behaviour during the kinds of short testing episodes utilised in the first phase. The qualitative data, coupled with the additional analysis incorporating self-reported motivations provided in Chapter 10, provided good evidence that body position, core grip, and blow height represent areas where evidence of self-learning is present, though not evident in all of the participants tested. In contrast, further analysis of the qualitative data highlight no trends indicating that early stage self-learning was occurring when considering the lateral movement of blow.

An interesting point to make regarding the issue of self-learning in time-constrained tasks is that, though it is enlightening to examine whether test participants self-learn in an unconstrained task environment, it was a specific aim to limit the degree of self-learning that test participants engaged in during the first phase. Indeed, when drafting the original methodology the principal investigator considered using the video footage of James Dilley as the means of instruction in the quantitative phase. Ultimately it was decided that the pie-slice indicator and verbal instruction were better suited to the test design, and the qualitative data validate this decision to an extent. A major aim of the quantitative phase was to minimise the effect of any factors that might affect the test participants' consistency. To this end, it was desirable that the test participants maintained, as far as was practicable, the same action when applying blows in both sets of conditions. Given the trends evident in qualitative data, however, it is clear that viewing video footage of an expert knapper may have resulted in at least some of the test participants changing their knapping action, which in turn could affect the degree of consistency achieved in the results.

11.4. Limitations and Implications for Future Study

A number of limitations were identified with the current study, many of which have implications for how future research in this area is conducted. Below I will consider the issues of cohort size and additional phases, the incorporation of multiple variables, the targeting of specific demographics, and possible improvements to the methodology stemming from the findings of the two phases of testing.

11.4.1. Larger Cohort/Additional Phases

A clear limitation to the present study concerned its scope, both in terms of the number of participants and the narrow area examined. Though the original intent was to test a larger cohort of test participants in the quantitative phase to allow statistical tests to be conducted, the principal investigator decided, given the concerns with the soundness of the methodology, that the development of a mixed methods approach incorporating a qualitative phase should take priority.

One could argue that the restricted scope of the study needs to be expanded in order to complete the last steps of the methodology of Evolutionary Psychology (steps 5 and 6). More data are required, for example, in order to eliminate rival explanations of skill acquisition in the task domain of stone tool production (i.e., those that argue that skill acquisition is facilitated by by-products of pre-existing cognitive structures or domain-general capacities for learning). Similarly, the test would need to be expanded to establish whether any identified trends are distributed cross-culturally, despite the presence of different environmental cues or social conditions. These drawbacks notwithstanding, however, the potential remains for conducting further phases of testing that could also incorporate the existing data.

Indeed, another way to expand the study besides increasing the cohort would be to introduce multiple phases of testing. For example, a potentially informative strand of research would involve designing a series of tests with interrupted time series, where time lapses occur between episodes of measurement (Field & Hole, 2006: 69). Such an approach may more accurately mirror the processes via which stone tool producing skills are acquired by novices.

11.4.2. Incorporation of Additional Variables

In addition to expanding the cohort of test participants, the study would also have benefited from examining other areas of the task domain of stone tool production. Though the quantitative phase focused exclusively on the variable of blow strength, for reasons stated in Chapter 10, it would be interesting to probe how well novice knappers perform where the successful completion of the task depends on the co-ordinated control of multiple factors. Expanding the scope of the study in this way, however, would arguably necessitate the introduction of multiple phases of testing, as alluded to above. Other variables from the task domain of stone tool production method could also provide a focus for future studies. The test design outlined in Chapter 8, for example, which was unfortunately beyond the scope of this study, could be developed for this purpose.

11.4.3. Clarifying Causal Relationships

Following considerations by the examiners during the viva voce further clarification was requested regarding the causal relationship between blow-strength judgement and stone tool production (i.e., how do we know that the properties of stone tools drove our judgements of blow strengths and not the other way around?).

This point proposes an alternative causal scenario, where the already existing 'wiring' of the brain and/or body promotes behaviours relevant to stone tool producing (like blow-strength judgements), but where the engagement in stone tool production over time need not have had any causal influence per se. Presumably the causal relationship envisaged promotes the idea that other percussive tasks, invisible in the archaeological record, were engaged in by ancestors in the Homo line and that the 'wiring' mentioned stemmed from these activities. This seems to follow since, as noted in Chapter 6, no capabilities closely resembling the percussive skills required for stone tool production are evident in the extant Great Apes.

One of the strengths of the methodology of Evolutionary Psychology is that it allows one to test between various hypothesised scenarios, and also encourages rival evolutionary explanations (such as this one) to be explored in full. For this study, the working assumption is that continual engagement in an adaptively beneficial task domain with unique problem types would have promoted the evolution of psychological mechanisms to facilitate the learning of such behaviours. A related assumption is that the properties of those psychological mechanisms will be closely attuned to the information-processing problems of the task domain. Were the human brain/body wired, as a result of other factors, to assess blow strength judgements generally, one could posit that there would be no reason for blow strength judgements ideal to a knapping task to be learned more efficiently than blow strength judgements that fall outside that range. So though I would agree that such a scenario is plausible, I would maintain that it would be unlikely to produce confounding results under test conditions.

One issue that this criticism has emphasised is that the study could have been strengthened, as noted above, by incorporating all the variables involved in the task domain, rather than blow strength judgement alone (the motivations for taking this approach were discussed in the introduction to Chapter 9). I would argue that, though it is conceivable that other tasks requiring blow strength judgements could have affect how the human mind and/or body is wired, this is much less feasible if one includes the simultaneous judgement of multiple factors: i.e., blow strength, blow angle, and blow precision. When all these factors are combined, the result is a task domain that is quite unique compared to any other.

Finally, I would like to address one last question raised by the external examiners relating to this issue, where they ask ‘perhaps stone tools have the properties they do because of the way our minds and bodies are wired, rather than the other way around?' This struck me as a curious question to ask, as it appears to imply that stone tool 'properties' can in some way vary (i.e., if our bodies were wired in a different way, the stone tools properties would reflect this). I would argue that this is plausible for method application, but not for technique. As noted in Chapter 6, the constraints imposed by the fracture mechanics of the raw materials used sets strict limits on what can and cannot be achieved. In choosing to remove a flake, the knapper needs to combine the factors of blow strength, angle and precision effectively or the result will be either no flake removal or an undesirable flake removal with features left on the core that complicate further work. The wiring of the mind/body, therefore, is always working within these constraints, and the properties cannot, by and large, be altered.[62]

I would argue that in the area of method this question makes more sense, since the step-by-step process of shaping by multiple flake removals involves more creative input from the knapper, and in such instances one can truly talk of 'properties' being imposed on the tool. This area would potentially provide a focus for future research, though for the present study the focus was limited to one element of the technique task domain.

11.4.4. Targeting Specific Demographics

Another way to expand the study would be to focus on specific demographics to identify potentially novel capabilities. For example, it would be interesting to use similar methodologies to target specific age ranges, particularly those of young children, to explore the hypothesis that there may be an ideal developmental 'window' for skill

[62] There are a few exceptions where the heating of raw materials alters the fracture properties to make them more favourable for knapping.

acquisition in stone tool producing behaviours (similar to that evident in the domain of language acquisition (Chomsky, 1959; Pinker, 1994)). The test designs described in this thesis would be well suited for this purpose in terms of sidestepping any ethical concerns with exposing young children to the well-established dangers associated with knapping. Further areas of interest may include an examination of potential gender differences in skill acquisition, or studies that examine the degree to which putative psychological mechanisms relating to technique and method are interdependent (for example, does skill learning in the method task domain require prior training in technique, or does it operate independently?).

11.4.5. Improvements in Methodology

Another area where limitations to the study were identified was in the methodology used in both the quantitative and qualitative phases of data collection process. Regarding the quantitative phase, for example, it was observed that a number of test participants either failed to adjust their blow strengths in response to the training or produced erratic results with no discernible pattern. Future applications of a similar methodology, therefore, would benefit from either providing more training for test subjects or incorporating multiple phases to allow more time to engender a behavioural change.

A further issue regarding the methodology was raised by the examiners during the viva voce regarding the potential limitations of using large industrial scales, which are designed for the purposes of weighing, to measure force. In response, I would firstly argue that precautions were taken to check after each testing session to ensure that the scales were producing consistent results. One can therefore be reasonably certain that no mechanical changes occurred in the equipment to adversely affect the data obtained. The use of scales was not without problems, however; indeed, the missing data points in the quantitative phase can be attributed to test participants' not allowing the scale adequate time to 'settle' between blows (i.e., approximately 2 seconds).

Secondly, though I would agree that more efficient and appropriate systems of recording downward force in an experimental setting are certainly conceivable, the decision to employ a top-loading industrial scale for measuring purposes in this instance was adopted in response to the restricted resources available to the Principle Investigator, coupled with an awareness of the primary aim of the study. To recap regarding the latter, to fulfil the primary aim of data collection the measuring equipment only needed to allow the collection of data that would allow the comparison of variance in blow strengths judgement in two sets of conditions. In this respect, the most important consideration in choosing appropriate measuring equipment was that it consistently record a value (regardless of units employed) proportionate to a downward force. A secondary aim of the study was to allow the data to be incorporated into future studies, and I would argue that this remains plausible. However, I would also acknowledge that this may not be feasible where a different experimental design, with different measuring equipment, were employed to measure an applied downward force.

Regarding the qualitative phase, I would argue that the methodology would have benefited from further feedback from the test participants regarding their motivations during the task. As noted above, additional feedback would have been very informative for the study in a number of areas, including the motivations behind participants' changes in core, grip hammerstone grip and lateral movement. For lateral movement, for instance, a possible trend evidencing the presence of self-learning may have been verified with supporting data in the form of verbal feedback. The study may have benefited in this instance from test participants completing a post-test questionnaire to further explicate their decision making during the task.

Alongside these limitations, however, a number of observations from the data can strengthen the methodology for future studies. The qualitative data relating to self-learning where video footage of actual knapping events was employed, for example, revealed that the use of video footage in the first phase may have prompted the test participants to make changes to their knapping action, which in turn would have introduced a potential bias in test designs requiring strict controls of variables between two sets of test conditions. Conversely, a study designed to further explore the influence of self-learning may benefit from the incorporation of video footage represents as a way to facilitate self-learning, as opposed to presenting guidance in more abstract form.

A further important insights from the qualitative data suggested that allowing test participants more freedom when making choices regarding body position and core grip would improve the test design. Though the quantitative data suggest that the equipment used in the first phase did not adversely affect the degree of consistency applied by test participants, it would nevertheless be desirable for future test designs to utilise measuring equipment that allowed participants to make choices regarding posture for the knapping task.

11.5. Overall Conclusions

In conclusion, the broad aim of this thesis was to apply the methodology of Evolutionary Psychology to the study of the task domain of stone tool production. The opening chapters provided a review of the pertinent literature from the fields of Evolutionary Psychology and cognitive archaeology. A notable finding from these chapters was the absence of research in cognitive archaeology explicitly adopting Evolutionary Psychology's methodological approach.

Chapters 4 and 5 drew on archaeological evidence to apply the first steps of the methodology of Evolutionary Psychology to the area of stone tool production. In order to achieve this, however, I argued that the problem types need to be delineated into specific domains. Technique and method provided an initial delineation in this respect, with technique being further demarcated into hard and soft hammer percussion, and method into the biface and Levallois. In chapters 4 and 5 these techniques and methods were then examined to explore the extent to which each can be considered a distinct adaptive problem. The definition and archaeological identification of each technique and method was discussed, together with the various associated adaptive advantages. Recurrence was also considered, both in terms of visibility in the archaeological record and variability in the task domains themselves. An important finding from these chapters was that the sense in which techniques and methods of stone tool production can be considered recurrent has connotations for carrying out the respective task analyses. Particularly, it was argued that, given issues regarding recurrence, it is unlikely a psychological mechanism will have evolved to address information-processing problem that are unique to a given method.

Chapters 6 and 7 consisted of task analyses of the techniques and methods under consideration. Regarding technique, the main findings concerned the identification of the variables that need to be attended to when using hard and soft hammer percussion. These variables are inherently linked to the conchoidal fracture properties of the lithic materials used, and can therefore be considered recurrent in a robust sense. Regarding method I argued that, due to the limited chronological occurrence of method types, a putative psychological mechanism could only evolve to address information-processing problems that are salient to all method types. Specifically, the conception and implementation of both long-term and short-term goals were proposed, including structures to embed/retrieve information to assist 'thinking through' method goals in order to build constellations of knowledge.

Chapter 8 focused on the issue of test design, beginning with a consideration of how the acquisition of stone tool producing capabilities can be tested in principle from the perspective of Evolutionary Psychology. I argued that the conchoidal fracture properties of the raw material represented the most relevant cause and effect relationship of the task domain, and that testing should focus on how efficiently novices learn in EEA conditions that closely mimic the task domain, verses non-EEA conditions where the parameters of the task deviate from those conditions. Practical test designs adopting this approach were also proposed to examine the technique and methods task domains.

Chapter 9 provided a detailed account of a methodology adopting a mixed-method test design incorporating both quantitative and qualitative phases. The quantitative phase focused on examining novice knappers' ability to consistently apply appropriate blow strengths in a knapping task. In response to observations made in the quantitative phase, the qualitative phase was designed to explore whether the test equipment used affected the test subjects' ability to complete the knapping task, and whether self-learning was feasible in the short time-frames used in testing. Chapter 10 presented the data collected in the quantitative and qualitative phases according to the methodology outlined in chapter 9.

Finally, the present chapter provided a critical evaluation of the findings together with a consideration of the limitations of the study and implications for future research. The overall results from the quantitative phase were assessed in light of two predicted trends in the data. The first trend, which proposed that test subjects would overestimate the blow strength required when using their own judgement, was evident for 8 of the 12 test subjects. For the remainder, 2 test subjects produced blows of a similar strength in both tasks, and 2 test subjects produced no discernible pattern.

The second predicted trend (i.e., the directional hypothesis) was that test participants would displayed better judgement (determinable through greater consistency) when applying blow strengths that are equivalent to those typically encountered in a knapping task, as opposed to those blow strengths that seem intuitively appropriate. Though it was observed that 7 of the 12 test participants performed as the directional hypothesis predicted, there was much discrepancy within this overall trend. A sizeable difference in terms of consistency in accordance with the directional hypothesis was evident in 3 test subjects, with a slight difference being observed for 4 test subjects. Conversely, 3 test subjects produced sizeable differences in consistency that were the opposite of that predicted, with a slight difference being observed for 2 test subjects.

Regarding the qualitative phase, though the data documented some trends that suggested test subjects may have spontaneously chosen to approach the knapping task differently in the absence of the measuring equipment used, there was arguably no evidence to support the view that the test subjects were impeded in terms of applying consistent blows in the first phase. For body position, the qualitative data evidenced test subjects making choices that were not compatible with the experimental conditions of the first phase (i.e., that the measuring equipment would have presented an impediment). However, when these findings were cross-checked with the quantitative data in the first phase, no correlation was evident in the standard deviation scores to suggest performance was impaired.

Similarly, for core grip, the qualitative data suggested that a majority of test subjects initially adopted grips that were not compatible with the experimental conditions of the first phase. Again, however, comparisons with the quantitative data suggest that it is unlikely that the equipment used in the first phase had an adverse effect on the performance of test subjects. This conclusion is further support by evidence from the lateral movement of blow, which suggested that changes in core grip did not result in significant increases or decreases of lateral movement of blow; one could therefore infer a degree of continuity in the knapping action applied. Though I would argue that any constraints introduced did not skew the data collected in the first phase, it would be desirable for future test designs to offer test subjects more options in terms of the body position and core grip.

A number of trends identifiable in the qualitative data support the view that early stage self-learning occurs during the kinds of short testing episodes utilised in the first phase. For both body position and core grip, the qualitative data suggests that some, but by no means all, test subjects exhibited self-learning during the short time-frames used. For blow height and lateral movement of blow, there are similar indications that some test subjects adapted their behaviour in response to the viewed footage of the expert knapper.

Various limitations were discussed relating to the study, many of which have implications for future research adopting a similar approach. It was argued that the study would have benefited from a larger cohort of test participants to allow appropriate statistical tests to be conducted. Though a larger cohort was planned in the initial phases of testing, the necessity of adopting a mixed-method approach and limited resources resulted in the study's scope being restricted in terms of cohort size. Further areas where the study has the potential to be expanded were also discussed, for example by introducing multiple phases of testing, incorporating additional variables relating to technique, conducting tests within the area of stone tool production methods, and targeting specific demographics.

A number of further implications for future studies were identified relating to the methodology employed. For example, it was noted that the qualitative data would have benefited from further clarification in the form of a post-test questionnaire to examine the motivations underlying behavioural changes in more detail. Trends identifiable in the quantitative data also suggest that a longer period of instruction may have been required for some of the test participants. The potential influence of self-learning during the testing process was also highlighted as an area that requires consideration in future studies, particularly where variables between two experimental conditions needs to be closely controlled.

In closing, it is hoped that this thesis goes some way to demonstrating the mutual benefits of interdisciplinary research combining the methodologies of cognitive archaeology and Evolutionary Psychology. I would argue that cognitive archaeology has much to gain in terms of the alternative perspective offered by Evolutionary Psychology. Particularly, the proposal that novel cognitive capacities relating to stone tool production could exist within the human cognitive architecture has the potential to promote the development of alternative methods of testing and data collection, which in turn can challenge pre-existing assumptions within cognitive archaeology. This can only lead to a clearer understanding of cognitive abilities that would have been common place in ancestral environments, but which are virtually non-existent in modern contexts.

Similarly, it is hoped that this thesis demonstrates that the field of Evolutionary Psychology can be greatly enriched by a rigorous consideration of the archaeological evidence relating to a task domain such as stone tool production. Indeed, the archaeological data incorporated here proved invaluable for characterising the stone tool production techniques and methods under consideration, including areas such as the chronological occurrence of the behaviours, the associated adaptive benefits, the variables associated with knapping tasks, and the attendant cognitive demands.

Appendix

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PARTICIPANT INFORMATION SHEET (Version 1)

17 August 2016

Full Title of project: An examination of novice flint knappers' judgement of appropriate blow strengths for a hard hammer percussion task.

Name of Principal Investigator: Paul Dennington

You are invited to participate in the study outlined below into novice flint knappers' judgement of appropriate blow strengths for a hard hammer percussion task.

The experiment design has two phases. In the first phase an experienced knapper will produce a model hard hammer flake removal, and then record the blow strength used in this task by reproducing the blow on a top-loading scale. In the second phase, test participants with no experience of knapping will be invited to estimate the blow strength required to produce the flake removal exhibited by the model.

As an experienced knapper, I would like to invite you to participate in the first part of this study. You will be asked to produce an example of a hard hammer flake using the materials provided (i.e., flint cobbles, a hard hammer stone, protective gloves and goggles). You will then be asked to reproduce the blow strength used to remove this flake by striking a rubber block affixed to a top loading scale a total of 10 times. The data gathered during this phase will provide a comparison point for examining how inexperienced test participants judge blow strengths under guided and unguided conditions.

You are also free to ask any questions regarding the tasks described above at any point in the process.

You are also free to decide whether or not to participate in this study, and can withdraw at any point should you change your mind after agreeing to participate.

All data relating to the study will be stored on a password protected computer. Any vide of the study will be anonymised by recording only the dial of the top-loading scale.

All funding for the study is coming from the principal investigator. If you wish, the outcomes of the study can be forwarded to you on completion.

Contact details of principal investigator:

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Figure A: The participant information sheet (version 1) provided to the expert knapper, James Dilley, prior to the task definition phase.

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INFORMED CONSENT FORM FOR SUBJECTS
ABLE TO GIVE INFORMED CONSENT (Version 1)

17 August 2016

Full Title of project: An examination of novice flint knappers' judgement of appropriate blow strengths for a hard hammer percussion task.

Name of Principal Investigator: Paul Dennington

I confirm that I have read and understood the subject information sheet (Version 1) provided for the above study and have had the opportunity to ask any questions which have been answered fully. ☐

I understand that my participation is voluntary and I am free to withdraw at any time without giving any reason. ☐

I understand that any data I volunteer will be held in accordance with the principles of the Data Protection Act 1998. ☐

In order to acknowledge my contribution to this study, I agree to my name being disclosed in any publications (both published and unpublished) that follow. ☐

Compensation arrangements have been discussed with me. ☐

I agree to take part in the above study. ☐

Name of Participant……………………..........	Signature……………………………	Date………
Name of person taking consent…………………	Signature……………………………	Date………

Figure B: The informed consent form (version 1) provided to, and completed by, the expert knapper, James Dilley, prior to commencing the task definition phase.

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PARTICIPANT INFORMATION SHEET (Version 2)

17/08/2016

Full Title of project: An examination of novice flint knappers' judgement of appropriate blow strengths for a hard hammer percussion task.

Name of Principal Investigator: Paul Dennington

You are invited to participate in the study outlined below which aims to examine how accurately a test participant with no knapping experience judges the blow strength required for a hard hammer percussion task.

Previously, an expert flint knapper was asked to produce a model flake removal for the purposes of this experiment; the model consists of a single flake and the core from which it was removed. The strength of the blow used to remove the flake was also recorded at this stage. This was achieved by asking the expert flint knapper to strike a top-loading scale with the same force as was used to remove the flake.

The experiment you are being asked to participate in has two stages: first, you will be invited to strike the top loading scale with an ovoid hammerstone a total of 10 times using the kind of force that you estimate would be required to remove the flake from the core. You will be free to examine the model flake removal beforehand, though no other guidance as to the ideal force of blow required will be given at this stage.

In the second stage, you will be invited to repeat the task described in the first stage after a short period of training. The training will involve the principal investigator providing guidance as to the appropriate blow strength required (i.e., by advising as to whether more or less force is needed). The training will involve producing a further series of blows, though the exact number will dependent on how well the training goes. The desired outcome of the training is for the test participant to be able to reliably strike the top-loading scale with the approximate force indicated by the principal investigator.

Once the training is completed, you will be invited to produce a third series of 10 blows, this time without guidance, with the aim of replicating the desired blow strengths achieved in the training.

You are also free to ask any questions regarding the tasks described above at any point in the process.

You are also free to decide whether or not to participate in this study, and can withdraw at any point should you change your mind after agreeing to participate.

All data relating to the study will be stored on a password protected computer. Any video recordings of the study will be anonymised by recording only the dial of the top-loading scale.

All funding for the study is coming from the principal investigator. If you wish, the outcomes of the study can be forwarded to you on completion.

Contact details of principal investigator:	Paul Dennington, Dept of Archaeology, Durham University, DH1 3LE Tel: 01913341100 E-mail: p.j.dennington@durham.ac.uk

Figure C: The participant information sheet (Version 2) provided to 6 of the test participants prior to testing.

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PARTICIPANT INFORMATION SHEET (Version 3)

17/08/2016

Full Title of project: An examination of novice flint knappers' judgement of appropriate blow strengths for a hard hammer percussion task.

Name of Principal Investigator: Paul Dennington

You are invited to participate in the study outlined below which aims to examine how accurately a test participant with no knapping experience judges the blow strength required for a hard hammer percussion task.

The experiment you are being asked to participate in has two stages. In the first stage you will be invited to strike the top-loading scale with an ovoid hammerstone a total of 10 times as consistently as possible. The principal investigator will provide a guide as to how hard you should hit the scale using a card 'pie-slice' to indicate the ideal zone on the scale within which the needle should fall. You will be allowed a period of time to practice this task until you feel you able to reliably strike the top-loading scale with the force indicated.

In the second stage, you will be presented with a model consisting of a single flint flake removal. This flake was removed from the core by an expert flint knapper for the purposes of this experiment. With reference to this model, you will be invited to strike the top loading scale a further 10 times using the kind of force that you estimate would be required to remove the flake from the core. You will be free to examine the model flake and core beforehand, though no other guidance as to the force of blow required will be given.

You are also free to ask any questions regarding the tasks described above at any point in the process.

You are also free to decide whether or not to participate in this study, and can withdraw at any point should you change your mind after agreeing to participate.

All data relating to the study will be stored on a password protected computer. Any video recordings of the study will be anonymised by recording only the dial of the top-loading scale.

All funding for the study is coming from the principal investigator. If you wish, the outcomes of the study can be forwarded to you on completion.

Contact details of principal investigator:	Paul Dennington Dept of Archaeology Durham University Durham DH1 3LE Tel: 01913341100 E-mail: p.j.dennington@durham.ac.uk

Figure D: The participant information sheet (Version 3) provided to 5 of the test participants prior to testing.

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INFORMED CONSENT FORM FOR SUBJECTS ABLE TO GIVE INFORMED CONSENT (Version 2)

17 August 2016

Full Title of project: An examination of novice flint knappers' judgement of appropriate blow strengths for a hard hammer percussion task.

Name of Principal Investigator: Paul Dennington

I confirm that I have read and understand the subject information sheet (Version 2) provided for the above study and have had the opportunity to ask any questions which have been answered fully.	☐
I understand that my participation is voluntary and I am free to withdraw at any time without giving any reason.	☐
I understand that any data I volunteer will be held in accordance with the principles of the Data Protection Act 1998.	☐
Compensation arrangements have been discussed with me.	☐
I agree to take part in the above study.	☐

Name of Participant………………………...........	Signature………………………………	Date…………………
Name of person taking consent…………………	Signature………………………………	Date…………………

Figure E: The informed consent form (Version 2) provided to, and completed by, each of the 12 participants prior to testing.

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PARTICIPANT INFORMATION SHEET (Version 4)

17/08/2016

Full Title of project: An examination of novice flint knappers' judgement of appropriate body position, grip and blow characteristics for a hard hammer percussion task

Name of Principal Investigator: Paul Dennington

You are invited to participate in the study outlined below which aims to record how test participants with no knapping experience approach a knapping task.

The experiment you are being asked to participate in has two stages. In the first stage you will be presented with a model consisting of a single flint flake removal. This flake was removed from the core by an expert flint knapper for the purposes of this experiment. You will be then given an ovoid hammerstone and a substitute core and invited to adopt the position you deem most appropriate for performing the knapping task indicated. You will then be asked to perform 10 strikes on the substitute core, maintaining as consistently as possible a blow strength that you deem sufficient to remove a flake as per the model viewed previously. This stage will be filmed to allow the principal investigator to extract data from the footage.

In the second stage, you will be asked to reflect on your chosen body position before viewing a short video of an expert knapper performing several flake removals from a core. You will then be invited to repeat the first phase of the experiment (i.e., adopt a position you deem most appropriate for performing a knapping task and perform 10 blows with a strength you feel would be sufficient to achieve the flake removal as per the model provided). Again, this stage will be filmed by the principal investigator.

You are free to ask any questions regarding the tasks described above at any point in the process.

You are also free to decide whether or not to participate in this study, and can withdraw at any point should you change your mind after agreeing to participate.

Test participants will remain anonymous, and all data relating to the study will be stored on a password protected computer. All video recordings and related data (e.g., screenshots) will be deleted once the relevant data has been extracted by the principal investigator.

All funding for the study is coming from the principal investigator. If you wish, the outcomes of the study can be forwarded to you on completion.

Contact details of principal investigator:

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Figure F: The participant information sheet (version 4) provided to the 12 to the test participants prior to testing.

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INFORMED CONSENT FORM FOR SUBJECTS ABLE TO GIVE INFORMED CONSENT (Version 3)

17 August 2016

Full Title of project: An examination of novice flint knappers' judgement of appropriate body position, grip and blow characteristics for a hard hammer percussion task

Name of Principal Investigator: Paul Dennington

I confirm that I have read and understand the subject information sheet (Version 4) provided for the above study and have had the opportunity to ask any questions which have been answered fully. ☐

I understand that my participation is voluntary and I am free to withdraw at any time without giving any reason. ☐

I understand that any data I volunteer will be held in accordance with the principles of the Data Protection Act 1998. ☐

Compensation arrangements have been discussed with me. ☐

I agree to take part in the above study. ☐

Name of Participant………….....	Signature……………………………	Date…………………
Name of person taking consent…….	Signature……………………………	Date…………………

Figure G: The informed consent form (Version 3) provided to, and completed by, each of the 12 participants prior to testing.

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